Department of Civil Engineering

Utilising waste products from Kwinana industries to manufacture low specification geopolymer concrete

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PREFACE

One technology that makes concrete without cement and does not have the associated carbon footprint is geopolymer concrete. This technology utilizes waste fly ash from power stations and mixes it with activating chemicals to form a binder with similar or better properties than cement.

Not only does this technology directly reduce carbon emissions by replacing cement it also utilizes the waste bi-product from power stations and prevents it from going to landfill.

Concrete is composed of coarse aggregates, sand and cementitious paste. It seemed possible to make geopolymer concrete from 100% waste. The aggregates would come from recycled concrete and hard brittle bottom ash from power stations, the sand would come from foundries and the fly ash binder would also come from the same power station as the bottom ash. All of these materials are waste and would all be dumped in landfill.

Where would one find all these waste materials in one place? The industrial suburb of Kwinana outside Perth is home to a large number of industries producing all these wastes.

To find products that have a specification that these materials would suit was a material with a relatively low specification, one such specification is the concrete masonry units' specification. For this to be adopted the mix design would then have to be altered to a drier type mix without any slump.

As recycling facilities do not make a range of products it was decided to crush the aggregates in the laboratory specifically for this research and to blend all the waste materials. Numerous combinations were blended, analysed and assessed to establish which blends would best suit the aims and scope of this research. Eventually three blends were selected that encompassed all the waste products.

To find the right mix design proved challenging as these masonry products generally require a mix to have zero slump. It was decided to test across all the known and analysed water to geopolymer solids ratios for each of the mixes and establish the best mix based on compressive strength, workability and slump

A known mix design based on research into low calcium Class F geopolymer concrete, developed at Curtin University using natural aggregates, was applied to these selected recycled waste mix designs . The benefit was to be able to compare the results of this research to a known result.

Flash setting, an unknown phenomenon in geopolymer concrete, did occur in the low water mixes, but in spite of this, geopolymer concrete was successfully manufactured. The compressive strengths were substantially lower than those of the design mix and more research is required in this regard, however an indirect relationship was observed between the amount of bottom ash and the compressive strength.

The high degree of LOI (loss of ignition) in both ashes, porosity of recycled aggregates, angularity, degree of fineness of the fines and flash setting are all possible factors influencing the properties of the geopolymer concrete. More research is recommended in a number of these areas to be able to understand and develop this technology further in order to make this a practical and robust technology in the quest to find solutions to our warming planet and our changing climate.

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1. INTRODUCTION

1.1 GENERAL

Kwinana is an Industrial suburb of Perth and is home to some of the largest industries in the State of Western Australia. Industries include a Power Station, iron, nickel and aluminium smelters, foundries, cement manufacturing plant, chemical plants and other general industry. In the neighbouring industrial areas which fall within the Kwinana industrial precinct, Cockburn and Henderson too are home to large foundries, cement manufacturing, quarries and landfill waste processing facilities.

Kwinana Industries Council (KIC) is a body set up to coordinate and assist in environmental issues within the industrial community of Kwinana as well as promoting synergies between different industries where bi-products of one industry can be used as input resources for another industry. Part of this strategy is finding use for the fly ash and bottom ash generated from the Kwinana Power Station. This Research is not in any way connected to KIC, however, the benefits of such a synergistic approach is what this research aims to achieve.

The benefits of industry are known to all; however the by –products or waste generated by industry is a subject that is preferably avoided. However, as time has progressed and industry has expanded, more and more of this waste is being generated and accumulated.

The developed countries of the world, and now the developing countries, are realizing that as populations expand, the value of land becomes more and more valuable. In the past it was considered an easy and simple process to dig large

holes and bury this waste. This had a number of benefits: it was cheap, easy and once buried was out of sight. However as economies expand and land becomes more valuable, the landfill solution becomes more expensive. Other factors such as chemical pollutants (which are toxic to humans and animals), were leaching and contaminating the water systems and eventually getting back into the main stream water supply which had, and can have, a health implication.

These landfill areas, once full, are not suitable for human or agricultural use for some time. This means that in places where land is valuable or in short supply, it can lead to social and economic problems.

Developed economies such as United States of America, Europe and now Australia have begun to realize that there is a very important and urgent need to recycle waste. Besides the land, health and social issues there is economic benefit in doing so. By adopting regulations incentivizing or even forcing industry to participate in recycling, the demand for primary materials is reduced and the existing but finite resources are preserved well into the future.

Quarries, mines and farms take up an enormous amount of land area. By recycling we limit the need to dig bigger holes or denude virgin forests. The earth's surface area is finite and so are its resources, therefore the more committed nations and people become to reducing consumption of primary resources and to recycling, the longer the existing resources will be maintained.

Opposition to recycling from established business and industry has been prevalent for a long time due to large capital investments that have been made in the past and proposed for the future; however, particularly due to the attention of greenhouse gas and its dire consequences for the planet, business and industry are developing an appreciation for the need to seek alternatives in reducing the emissions of CO2. Efforts are being made to improve land

utilization and reduce unnecessary cultivation, particularly of rainforests. What was once seen as an irritating nuisance, recycling and its benefits are now slowly being embraced.

It has now recognised that the manufacturing and production of cement is one of the most prolific producers of Carbon Dioxide (CO2) – second only to the production of electricity. Concrete, which uses cement and aggregate, is the most commonly used man-made material and the second most utilized commodity (second only to water) on the planet. It is therefore understood that any alternative process or product which can reduce the use of cement will have a direct benefit in reducing greenhouse gas emissions.

Geopolymer concrete is believed to be a copy of a natural process of rock formation that nature used many millions of years ago to create the rock formations we see on earth today. Prof. Joseph Davidovits has proposed the theory that the Ancient Egyptians used a concept very similar to that proposed by him to form the large blocks that were used in the construction of the Pyramids at Giza. Prof. Davidovits termed the process of producing a concrete from aggregates, silica and aluminium rich materials in an alkali medium - Geopolymer Concrete. In Davidovits' research, Metakaolin was used as the main source material. Metakaolin is calcined natural occurring clay which is rich in aluminium and silica. At Curtin University's Department of Civil Engineering in Western Australia, Prof. Vijay Rangan proposed an alternative material such as Fly Ash, in particular low Calcium Class F fly ash, since it exhibited high amounts of silica and aluminium in the proportions necessary to facilitate the required polymeric reaction. He set about formulating a method and procedure to make concrete from low calcium fly ash. Together, Hardjito, working under Prof. Rangan, and Professor Rangan himself, developed GC1 (Hardjito and Rangan 2005) which was the Development and Properties of Low Calcium Fly Ash Based Geopolymer concrete. Further research under Prof Rangan's

guidance together with Wallah. developed the GC2: the Long Term Properties of Low Calcium Fly Ash Based Geopolymer Concrete.(Wallah and Rangan 2006)

Fly Ash and bottom ash for all intents and purposes are regarded as waste products derived from the burning of pulverized coal. The coal is used as a fuel for generating electricity in power stations. Verve Energy's Kwinana Power Station in Kwinana runs on coal, gas and diesel to generate electricity. Fly ash produced from Kwinana Power station is dumped in landfill.

In the production of iron and steel, lime is added as a flux assisting the smelting process. As a result of this process a waste or bi product commonly known as lag is formed. This slag, when ground or granulated in the cooling process, can be used by a number of industries. As more and more uses are found for slag and the demand has grown immensely, slag is loosing its classification as a waste product. However, Hismelt, an iron smelter in Kwinana, has been stockpiling slag for some time and are currently undertaking processes to find ways to utilize this material.

Foundries, in particular sand casting foundries, use sand in the making of moulds in which various metals are poured to form castings. Once the process is complete, this sand can be recycled but in most cases is discarded as waste and regularly finds its way to landfill. Almost all of the sand from the foundries in the Kwinana precinct is dumped at the Cockburn Landfill Waste Facility

As cities grow and expand outwards, in what is commonly termed urban sprawl, the inner city usually decays. As the need for space near the city arises so do real estate values and consequently so does the need to demolish and rebuild - a naturally evolving process. The demolition of most buildings and civil structures made from concrete consists of 75% aggregate which is predominantly being dumped in landfill. The majority of the aggregates and the reinforcing steel found in this demolition waste can be recycled but currently, as

in the past, it has been easier to bury in landfill. As landfill becomes scarcer and therefore more expensive, a realization that these materials have value is emerging. Even though the signs are encouraging, government regulation and incentives are lagging.

1.2 AIMS AND OBJECTIVES OF THIS RESEARCH

Portland cement concrete or OPC have been using recycled concrete aggregates as a material in normal concrete; however the amount of recycled concrete aggregates prescribed is not greater than 30%.

Industries in the Kwinana industrial precinct produce waste products that all posses potential as ingredients in the manufacture of geopolymer concrete.

Concrete masonry products for both the building and civil industry require lower strength than structural concrete and therefore the amount of recycled aggregate that can be used can be increased.

The aims of this research are:

1. To manufacture geopolymer concrete according to GC1 (Hardjito and Rangan 2005) using 100% recycled aggregate sourced within the Kwinana Industrial precinct.

2. Using low calcium Class F fly ash waste from Kwinana Power Station as the alumino-silicate source material in the manufacturing of geopolymer concrete.

3. To determine the best method of crushing recycled concrete aggregate using a combination of crushers in order to achieve a specific target

grading and stone shape to be used as an aggregate in geopolymer concrete.

4. To investigate and determine the optimum blend of recycled concrete aggregate, foundry sand, slag and bottom ash in order determine the most suitable aggregate mix design that can be used for the manufacturing of geopolymer concrete.

5. To determine a mix design with particular reference to a ”dry mix” i.e. zero slump suitable to manufacture geopolymer concrete masonry products with a unconfined compressive strength of 5 MPa in accordance with Australian standard AS/NZ 4455.1:2008.

1.3 SCOPE OF WORK

The research utilized low calcium fly ash from a single source at Verve Energy’s Kwinana Power Station. This Fly ash was used in the manufacture of geopolymer concrete based on the method set out in GC1.(Hardjito and Rangan 2005)

The mix designs, testing and analysis used in this research are the same as those developed for the manufacture of OPC.

Machinery used in crushing was exact replicas of industrial crushers used in the civil and mining industries but on a smaller scale.

2. LITERATURE REVIEW

2.1 OVERVIEW

Portland cement concrete and its properties are covered extensively in books such as that of A.M. Neville[1], but recycled concrete, particularly geopolymer concrete are fairly recent developments, covered mainly by research papers and online articles. The literature and information for this research has been obtained from internet websites, articles, books, published papers and Australian Standards.

2.2 ENVIRONMENTAL ISSUES

2.2.1 GLOBAL WARMING

For some time now it has been recognized that the earth's temperature has been increasing and this has been in part attributed to the greenhouse gas effect, which simply put states that gases, in particular Carbon Dioxide (CO2), form a layer in the upper atmosphere which have an insulating effect, trapping heat between this layer and the surface of the earth resulting in the temperature of the earth and atmosphere increasing. A significant factor in this process occurring is an increase in human population growth, its consumption of energy and the associated carbon dioxide released form this energy consumption; as well as the direct result of changing the land cover for agriculture, mining, industry and housing. (Vitousek 1994; Mehta 2001)

As the human population of the world increases so does the need for housing and infrastructure increase and consequently so does the use of cement.

2.2.2CONCRETE AND CLIMATE CHANGE

Ordinary Portland Cement (OPC) is the main ingredient in the manufacturing of concrete which is the most extensively used construction material in use today. OPC results from the calcination of limestone and silica. Producing a ton of Portland cement requires about 4 GJ of energy and Portland cement clinker manufacture releases approximately one ton of carbon dioxide into the atmosphere.(Davidovits 1994; Mehta 2001)

The world's annual cement production of 1.6 billion tones accounts for about 7% of the global loading of carbon Dioxide into the atmosphere.(Mehta 2001) Global cement production is expected to increase from 2283 mta in 2005 to 3560mta by 2020 which represents an increase of 56% on an average estimate.(Consultants 2006). If we take the correlation of 1 ton CO_2 for every ton of cement, then by 2020 the amount of CO_2 being placed in the atmosphere from the production of cement alone will be 3.6 billion tones annually.

Based on these predictions the need for an alternative to replace, or reduce this impact, is necessary.

2.3RECYCLED RESOURCES

2.3.1 RECYCLED CONCRETE

"6% of the global flow of materials, some 500 billion tones a year end up as desired products while most of the virgin materials are returned to the environment as harmful solid, liquid and gaseous wastes". (Hawken, Lovins, and Lovins 1999; Mehta 2001)

The United States of America and Europe have been recycling concrete for some time now and in Australia momentum is gathering, as is evident with the release of an Australian Standard HB 155-2002 Guide to the use of recycled concrete and masonry materials (Standards Australia 2002) In Australia the State of Victoria is taking a leading role

Studies in Europe show various alternative recycling strategies were compared according to certain criteria particularly earmarking energy usage. What became apparent is that even though recycling requires considerable energy and time, the conclusion was unequivocally supportive of recycling. (Roussat, Dujet, and Méhu 2009; Blengini 2009)

Demolition of buildings and infrastructure is normally a matter of course as populations expand and cities decay from inside out. People want new rather than old or functional and so zoning and land use change. The major driver of demolition is that the design life of buildings and structures is being reached prematurely. (Mehta 2001; Tabsh and Abdelfatah 2009) Recently it has become evident that close attention is being paid in determining the life cycle of buildings as well as the materials used in their construction - what is to become of these materials when their life cycle is reached. (Blengini 2009)

Presently most concrete manufactured from recycled concrete aggregate contains only a certain percentage of recycled aggregate, the rest being virgin aggregates. This is because the Australian Standard HB 155-2002 (Standards Australia 2002) advocates a 30% maximum substitution of RCA in new concrete. This 30% limit is believed to have no effect on the properties of the new concrete. The reason for substituting up to 30% is that it is believed that most concrete made from recycled concrete will be for structural purposes. In products such as masonry bricks, block and pavers as well as certain precast products the compressive strengths specified are relatively low (3-5MPa) compared to that of structural concrete and therefore it is believed that 100%

substitution is considered possible. The aim of this research is to use 100% of recycled concrete aggregates (RCA).

RCA is shown to have higher moisture absorption than that of virgin aggregates. Sumed Nandani Paranavithana (Paranavithana and Mohajerani 2006) states that porosity of RCA is the main property which prevents using RCA as a major construction material. Australian Standard HB 155-2002 (Standards Australia 2002) describes the moisture absorption in RCA as more difficult to predict than in conventional concrete. However, according to GC1 (Hardjito and Rangan 2005), water does not play a chemical role in geopolymer concrete which could allow RCA to be used at much higher percentages.

The cement mortar attached to the recycled concrete, as well as the mortar particles themselves, especially those present in the fine aggregate portion, are more porous than the natural aggregate. The resultant water demand is often not constant due to the various source materials that make up the recycled aggregate and therefore it is hard to predict accurately. (de Juan and Gutiérrez 2009) (Padmini, Ramamurthy, and Mathews 2009)

It is often advocated that only the coarse fraction i.e. above 4.75mm be used in concrete made from RCA as the water demand is lower and more predictable and the workability is higher. (Standards Australia 2002; Padmini, Ramamurthy, and Mathews 2009) The larger the aggregate size the less the percentage of mortar attached to the surface and therefore large recycled aggregates have less influence on the finished properties of the new concrete .(Padmini, Ramamurthy, and Mathews 2009)

Recycled concrete aggregates made from parent concrete with minimal contamination of brick, render and other masonry material can be used effectively as structural concrete. If the recycled concrete aggregate is made from parent concrete of strength exceeding 50MPa then this material can be

considered to behave in the same manner as natural aggregate.(Tabsh and Abdelfatah 2009)

2.3.2 FOUNDRY SAND

Foundry sand is a bi- product from ferrous and non-ferrous foundries. Recycling foundry sand is practiced mainly by large foundries as the equipment is expensive and the recycled sand's quality deteriorates with each time resulting in a decrease in quality and therefore recycled sand can not be used on the face of castings. This poses an added problem of becoming a two stage process. Sand can only be recycled a number of times and then must be disposed of. As sand in Australia at present is relatively cheap and the landfill costs are comparatively low the trend is to dispose of the spent sand in landfill. Foundry sand is considered in some circles as hazardous waste as it has been treated with chemicals, resins and other binders in the moulding process and these chemicals have the potential to leach out over time and should not be disposed of in general landfill.

As foundry sand is generally of high quality (Siddique, Schutter, and Noumowe 2009) it can be used as a partial replacement for fine aggregate in concrete. (Today et al. 2004) (Javed, Lovell, and Hollenbeck 1994)

Tests undertaken recommend a partial replacement of between 25% to 30% for fine aggregate in the manufacture of low strength Portland cement products as well as for concrete bricks and blocks and pavers. (Naik et al. 2003.) (Tikalsky, Smith, and Regan 1998) However they go on to say that 100% spent foundry sand could be used but there was a strength decrease when more than 50% of fine aggregate was replaced with foundry sand.(Khatib and Ellis 2001)

2.3.3 FLY ASH

Fly ash is the finest of coal ash particles. It is called "fly" ash because it is transported from the combustion chamber by exhaust gases. Fly ash is the fine powder formed from the mineral matter in coal, consisting of the noncombustible matter in coal plus a small amount of carbon that remains from incomplete combustion. Fly ash is generally light tan or grey in color and consists mostly of silt-sized and clay-sized glassy spheres. This gives fly ash a consistency somewhat like talcum powder. Properties of fly ash vary significantly with coal composition and plant-operating conditions.

Fly ash can be referred to as either cementitious or pozzolanic. A cementitious material is one that hardens when mixed with water. A pozzolanic material will also harden with water but only after activation with an alkaline substance such as lime. These cementitious and pozzolanic properties are what make some fly ashes useful for cement replacement in concrete and many other building applications. (University of North Dakota 2008)

This fly ash is collected and sluiced in water to settling ponds where it will remain unless processed. There are various ways of collecting and transporting fly ash, but these fall outside the scope of this research.

In Ordinary Portland cement manufacturing, fly ash is considered a pozzolan, a material which, when combined with calcium hydroxide, exhibits cementitious properties. In Geopolymer concrete, fly ash (80% - 85% Class F) is rich in silica and aluminium which are necessary to engage a chemical reaction in an alkaline medium and result in polymerization. (Davidovits 1994, 1999; Hardjito and Rangan 2005; Wallah and Rangan 2006)

Fly ash is normally grey in colour and can be light dark or even beige depending on the type of coal and the efficiency of combustion. Fly ash can normally be classified in one of two classes viz. ASTM Class F (low calcium CaO<10%) or ASTM Class C (high calcium CaO >20%). The American Society for Testing and Materials (ASTM) is probably the most widely recognized and used national standards-setting organization in the United States for engineering-related materials and testing.

Table 1 shows the chemical and physical requirements listed in the ASTM C618 (University of North Dakota 2008)

Table 1: ASTM Specification for class F, C and N fly ash

ASTM specification C618 for chemical and physical specifications

	Mineral Admixture Class		
	N	F	C
Chemical Requirements			
Silicon dioxide, aluminum oxide, Iron oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$) min. %	70	70	50
Sulfur trioxide (SO_3), max. %	4.0	5.0	5.0
Moisture content, max. %	3.0	3.0	3.0
Loss on ignition, max. %	10.0	6.0[a]	6.0
Available alkalies as Na_2O, max %[b]	1.5	1.5	1.5
Physical Requirements			
Fineness, max. % retained on 325-mesh sieve	34	34	34
Strength Activity Index			
Portland Cement			
7-day, min. % control	75[c]	75[c]	75[c]
28-day, min % of control	75[c]	75[c]	75[c]
Water requirement, max. % of control	115	105	105
Autoclave expansion, soundness, max. %	0.8	0.8	0.8

A. The use of Class F pozzolan with up to 12% loss on ignition may be approved by the user if either acceptable performance records or laboratory test results and made available.
B. Applicable only when specifically required by the purchaser for mineral admixture to be used in concrete containing reactive aggregate and cement to meet a limitation of the alkali content.
C. Meeting the 7 or 28 day strength activity index will indicate specification compliance.

The ASTM C618 specification is the most widely used because it covers the use of fly ash as a pozzolan or mineral admixture in concrete. The three classes of pozzolans are Class N, Class F, and Class C. Class N is raw or calcined natural pozzolan such as some diatomaceous earths. Class F is pozzolanic fly ash normally produced from burning anthracite or bituminous coal. Class C is pozzolanic and cementitious fly ash normally produced from burning lignite or subbituminous coal. (University of North Dakota 2008)

An important method of determining the ability of the fly ash to meet the application required is the Si/Al ratio or SiO_2/Al_2O_3 ratio. For this research an SiO_2/Al_2O_3 ratio of 2 is applicable. (Davidovits 1999)

“The main characteristics of a fly ash for leading to a material with optimal binding properties by alkali activation are: percentage of unburned material lower than 5%; Fe_2O_3 content not higher than 10%; low content of CaO; content of reactive silica between 40–50%; percentage of particles with size lower than 45 μm between 80 and 90%; and also high content of vitreous phase”.(Fernández-Jiménez and Palomo 2003)

The particle size of the fly ash has an influence on its reactivity, meaning the smaller the particles the more they will react with the alkali activator, hence the greater the polymerization and resultant strength.

The fly ash from Kwinana Power Station is classified as Class F but of inferior quality due to its high percentage of unburnt carbon (LOI) between 9% and 20%.

According to a Curtin University paper on Fly Ash Stabilisation of Fine Grained Soils (Nikraz H. R. 2007)[9], the fly ash which has been sluiced to landfill in water has lost a large portion of its pozzolanic properties and is not suitable for Portland cement concrete, however it can possibly be effectively used in geopolymer concrete as its remains a rich source of Si and Al. The fly ash is moist in stockpile but whether this will have an effect is to be determined. Drying the fly ash is an option; however this would require energy which could be considered a drawback in terms of CO2 emissions.

2.3.4 BOTTOM ASH

Coal bottom ash and fly ash are quite different physically, mineralogically, and chemically. Bottom ash is a coarse, granular, incombustible byproduct that is collected from the bottom of furnaces that burn coal for the generation of steam, the production of electric power, or both. Bottom ash is coarser than fly ash, with grain sizes spanning from fine sand to fine gravel. The type of byproduct produced depends on the type of furnace used to burn the coal. (University of North Dakota 2008)

For the average type coal combusted during the generation of electricity approximately 1% ends up as bottom ash.(KIC 2005) This bottom ash is then collected and transported or sluiced to settling ponds where it will remain unless processed.

Bottom ash generated from the Kwinana Power Station has a history of being placed in landfill. In comparison to fly ash not as much research has been undertaken on bottom ash.

Bottom ash has a grading similar to coarse sand and can be successfully used as an aggregate replacement as described in Beneficial Use of Non Toxic Bottom Ash (EPA 1994) and Bottom Ash: An Engineering Material (Seals, Moulton, and Ruth 1972). Some bottom ash, depending on the degree of crushing, can be used as a coarse aggregate as well.

Another beneficial property of bottom ash is that it is high in SiO_2 and $Al2O_3$ which are prerequisites for manufacturing geopolymer concrete. The advantage of bottom ash is that it can be used as an aggregate or as a supplier of Al and Si, or both. Where this material has been used as an aggregate it has been used as a coarse and as a fine aggregate. If used as a supply of Al and Si ions the bottom ash will have to undergo crushing and milling in equipment such as a

ball mill to be fine enough, hence reactive enough to the alkali medium for polymerisation to take place. (Slavik et al. 2008)

In terms of being used as a coarse aggregate it can be characterized as a light weight aggregate, as it is a porous material, and had been used as such in the US as a lightweight aggregate in the manufacture of masonry blocks.(Center 2007)

In Brazil an investigation into the use and influence of bottom ash as a fine aggregate in OPC showed that the porosity being inconsistent influenced the water demand of the mix and therefore the mix design could not be accurately determined.(Andrade, Rocha, and Cheriaf 2009)

Table 2: Typical mechanical properties of bottom ash and boiler slag.

Property	Bottom Ash	Boiler Slag
Maximum Dry Density kg/m^3 (lb/ft^3)[7]	1210 - 1620 (75 - 100)	1330 - 1650 (82 - 102)
Optimum Moisture Content, %[7]	Usually <20 12 - 24 range	8 - 20
Los Angeles Abrasion Loss %[4]	30 - 50	24 - 48
Sodium Sulfate Soundness Loss %[4]	1.5 - 10	1 - 9
Shear Strength (Friction Angle)[6]	38 - 42° 32 - 45° (<9.5 mm size)	38 - 42° 36 - 46° (<9.5 mm size)
California Bearing Ratio (CBR) %[6]	40 - 70	40 - 70
Permeability Coefficient cm/sec[6]	10^{-2} - 10^{-3}	10^{-2} - 10^{-3}

2.3.5 SLAG

Slag, whether blast furnace slag (BFS), or granulated blast furnace slag (GBFS), has gained in popularity and as a result is finding a permanent demand in conventional concrete and cement production. It is debatable whether it can still be classed as a waste product.

BFS due to its rock like appearance and properties can be crushed to form a coarse aggregate which can be effectively used in concrete. GBFS, being much finer, is a good substitute for fine aggregate or coarse sand replacement.

BFS is also rich in Si and Al and therefore has the potential to also enhance the geopolymer chemical reaction. (Cheng and Chiu 2003; Davidovits 2002)

Due to its increasing popularity BFS and GBFS are in short supply, especially on the East coast of Australia. In Western Australia a pig iron smelter in Kwinana has a large stockpile of approx 50 000 tonnes and are investigating possibilities for its use.

Fig 1: Slag stockpile at Hismelt Kwinana

The current unavailability of slag in a form that can effectively be used in trials for making geopolymer concrete has resulted in slag being omitted from this research.

2.4 GEOPOLYMER CONCRETE

Geopolymer concrete in theory has been around for 49 years, Glukhovsky first investigated alkali activated cementitious systems in 1959 (Glukhovsky 1959) but only recently under commitments based on the Kyoto Protocol, related to greenhouse gasses reductions, has its real value become apparent. (Duxson et al. 2007)

Geopolymers are formed when the Al and Si in the source material, natural clays (kaolinite) or industrial wastes (fly ash), react in an alkaline medium to form polymeric ring and chain structures. (Davidovits 1994, 1999; Hardjito and Rangan 2005) The chemical reaction is relatively fast and the resultant strength of these bonds can be compared favourably to that of Portland cement, even though the chemical process is different.

Geopolymer concrete is formed when the geopolymer paste is added and mixed with fine and coarse aggregates to form a concrete matrix.

Curtin University has undertaken extensive research with the development of GC1, GC2, GC3 and GC4 (Hardjito and Rangan 2005; Wallah and Rangan 2006; Sumajouw and Rangan 2006) which investigated the mix design, short term and long term properties and practical applications of geopolymer concrete made from Low Calcium Class F Fly Ash. The methods and results of this past research will be the foundation on which this research is based.

2.4.1 ALUMINO-SILICATE SOURCE MATERIALS

Geopolymer is a term given to a group of inorganic polymers by the French materials scientist Joseph Davidovits (Davidovits 1991).These materials are alkali-activated alumino-silicates. The high Si and Al ions react with the alkaline medium to form polymeric bonds similar in strength to those in ordinary Portland cement concrete.

Davidovits originally used metakaolin, a commonly available clay as his materials, Metakaolin is formed at high temperatures above 800 degrees Celsius resulting in calcination but the process involves substantial amounts of energy. Waste materials that have the potential for making geopolymer concrete are blast furnace slag, bottom ash and fly ash which are all rich sources of Silica (Si) and aluminium (Al). Davidovits defined applications of geopolymers according to their molar Si/Al ratio or SiO_2/ Al_2O^3. Based on this work our research requires a SiO_2/ Al_2O^3 of 2.

The two main types of fly ash are Class F (CaO<10%) and Class C fly ash (CaO >20%) have both been found to be suitable for use in geopolymer concrete. (Hardjito and Rangan 2005; Chindaprasirt, Chareerat, and Sirivivatnanon 2007)

Bottom ashes are also rich in Si and Al can also be used in geopolymer concrete, however they can be used as an aggregate or act as an alumino-silicate material.(Andrade, Rocha, and Cheriaf 2009; Slavik et al. 2008) In the former case, as an aggregate they are sometimes considered highly porous and therefore affect the water demand on the concrete. (Andrade, Rocha, and Cheriaf 2009). As a source of Al and Si they need processing in order to make them finer and hence more reactive to the alkaline activator.(Slavik et al. 2008)

Blast furnace slag (BFS), granulated blast furnace slags (GBFS), boilers slags and recently mine tailings (Pacheco-Torgal, Castro-Gomes, and Jalali 2008) have all been used successfully to produce geopolymer concrete.

2.4.2 ALKALINE ACTIVATING SOLUTION

For polymerisation to work the Al and Si ions react in an alkaline medium. This medium can either be sodium based (Na) or potassium based (K) or a combination thereof. The alkaline solution can be made up from the following:

- Sodium hydroxide (NaOH) or commonly known as Caustic Soda.
- Potassium hydroxide (KOH)
- Sodium silicate ($Na_2SiO_{3)}$ also known as **water glass** or **liquid glass**.
- Potassium silicate (K_2SiO_3)

GC1 research (Hardjito and Rangan 2005) chose to use a sodium based system entirely i.e. sodium hydroxide and sodium silicate. Hardjito and Rangan chose to use a Sodium (Na) based system because the chemicals are cheaper with the intention to keep the costs to a minimum and in so doing make the technology as economically viable.(Hardjito and Rangan 2005).

2.4.3 MIX DESIGN

The methods of design for ordinary Portland cement mixes, besides water cement ratio, all apply to geopolymer concrete.

Australian Standard HB 155-2002[3] specifies that all mix design testing and evaluation methods applying to virgin aggregates apply to recycled concrete aggregates as well.(Standards Australia 2002)

2.4.3.1AGGREGATES

2.4.3.1.1 GRADINGS / PARTICLE SIZE DISTRIBUTION (PSD)

In normal concrete the aggregates comprise approximately 70 to 80% of the weight of the mix. An aggregate can be described by its grading or psd (particle size distribution) curve which shows the mass retained or passing a particular set of sieve sizes. The distribution is shown on a logarithmic curve. The grading is then compared to an envelope representing the theoretical upper and lower limit of the maximum density, or maximum packing. The target grading is a grading curve that ideally would run between the upper and lower limits of the envelope. Should the aggregate grading represent this target grading then it can be assumed that the maximum amount of packing has been achieved. This means that the voids between the aggregates are filled by smaller particles so that the spaces between the individual particles are at a minimum. When this situation is achieved then the minimum amount of cement is required to achieve the target strength for a concrete mix.

From the psd, the aggregate can be divided into two distinct fractions i.e. those greater than 4.75mm (the coarse aggregate fraction) and those less than 4.75mm (the fine aggregate fraction or sand fraction).

On completion of the particle size distribution, the next step is to categorize the aggregates into coarse or fine aggregates and then to determine the mix proportions that will provide the best possible grading curve as set out in AS2758.1 (section 8).

2.4.3.1.2 BLENDING OF AGGREGATES

Aggregates most commonly have grading curves that fall outside the desired maximum packing envelope. In such instances if these aggregates are used

then they will require a binder content exceeding the optimum which is uneconomical. In such cases a process of blending aggregates of various sizes is undertaken to achieve and overall grading as close to the target grading as possible.

A.M. Neville's book Properties of concrete (Neville 1995) provides two methods for determining the blended aggregate proportions i.e. a mathematical calculation or a graphical method. These methods have their limitations with regard to a number of coarse and fine aggregates being blended and only really take into account the percentage passing two sieve sizes.

Software using various mathematical algorithms enables a comprehensive blending on all sieve sizes for up to 3 coarse aggregates and 3 fine aggregates at any one time.

As cement in the case of OPC concrete, and chemicals in geopolymer concrete are very expensive and contribute significantly to the overall cost of the concrete, considerable effort should be taken to blend aggregates in order to achieve maximum packing and hence reduce the amount of binder in the matrix.

2.4.4. GEOPOLYMER CONCRETE DESIGN

The design of the geopolymer concrete mixes in this research is based on the mix design of GC1and GC2 (Hardjito and Rangan 2005; Wallah and Rangan 2006) and is as follows:

- The aggregate's role in the matrix is same as in Portland cement concrete and comprises 75% - 80% by mass of the geopolymer concrete. Recycled concrete aggregates are assumed to be 10% lighter than natural aggregates. The fineness modulus of the combined aggregates has to be between 4.5 and 5.0

- Alumino-silicate source material, in this instance low-calcium class F fly ash, must have silicon and aluminium oxides present, the sum of which must be between 70 – 80% by mass of the total oxides present.

- Sodium hydroxide (NaOH) of concentration 8 Molar – 14 Molar. The higher the concentration of NaOH the higher the compressive strength of the geopolymer concrete.

- Sodium silicate (Na_2SiO_3) A53. The higher the ratio of sodium silicate to sodium hydroxide by mass, the higher the compressive strength of the geopolymer concrete.

- Ratio of sodium silicate to sodium hydroxide solution by mass of 2.5

- Ratio of alkaline liquid to fly ash of 0.35

- Water to geopolymer solids ratio of between 0.16 and 0.24.

- Superplasticiser (naphthalene sulphonate-based) of up to 4% of fly ash by mass.

2.4.5 MIXING OF GEOPOLYMER CONCRETE

- Sodium hydroxide and sodium silicate alkaline chemicals to be mixed 24hrs prior to mixing with aggregates.

- Aggregates are to be in saturated surface dry condition.

- Aggregates and fly ash are mixed for approximately 3 minutes prior to adding alkaline activator solution.

- Mixing of aggregates, fly ash and alkaline activator solution for a further 4 minutes.

- Casting and compacting are the same procedure as for normal OPC concrete

2.4.6 CURING OF CONCRETE

To facilitate the speed of the chemical reactions during polymerization, heat curing is advised, especially, in terms of sodium based systems.(Kovalchuk, Fernández-Jiménez, and Palomo 2007) At ambient temperatures above 23 degrees Celsius curing will take place but it is slow.

Heat cured geopolymer concrete can be either steam or dry cured. In sodium based systems dry curing achieves a higher compressive strength than with steam. (Hardjito and Rangan 2005) In all other systems covered moulds result in the highest strength followed by steam curing in open moulds and lastly by dry curing.(Kovalchuk, Fernández-Jiménez, and Palomo 2007)

GC1 (Hardjito and Rangan 2005) advocates steam or dry curing for a period of 24hrs at 60 degrees Celsius. Other research has used 75 degrees as the required temperature for a period of 48hours which has an increased strength benefit of 30 %; however a great deal more energy and time is required. (Chindaprasirt, Chareerat, and Sirivivatnanon 2007)

For the purpose of this research we will be using dry curing at 60 degrees Celsius and for a time period of 24 hrs.

2.5 LOW SPECIFICATION CONCRETE PRODUCTS

Low specification concrete products are mainly produced for the construction industry and comprise masonry/concrete bricks, blocks and pavers. These products are classified as low strength by the relatively low unconfined compressive strength criteria.

Australian standard AS/NZS 4455.1:2008 MASONRY UNITS, PAVERS, FLAGS AND SEGMENTAL RETAINING WALL UNITS. (Standards Australia 2008) specifies that the unconfined characteristic compressive strength of 5 MPa for hollow units, 3 MPa for solid and vertically cored units and 2.5 MPa for horizontally cored units.

There are other specifications that need to be considered like wall thickness so in order to ensure that all the specifications an unconfined characteristic strength of 5 MPa will be aimed for.

3. EXPERIMENTAL METHODS

3.1 INTRODUCTION

This chapter will outline the various methods of analysis and testing of materials.

The basis of all concrete whether it is OPC or geopolymer concrete requires a mix design. In this design we will analyse the grading or psd of all the aggregate components as well as the optimum blend. Alumino-silicate source material as in class-F fly ash from Kwinana Power Station and alkali activator solution will be discussed.

3.2 MATERIALS

3.2.1 RECYCLED CONCRETE AGGREGATE

The recycled concrete aggregate (RCA) sampling was taken from the recycling plant at Cockburn Recycling landfill site run and managed by Brajkovich Demolition. Crushing is basically a primary and secondary operation using a mobile jaw crusher. All large building waste feedstock, up to 1m, is crushed to a -50mm +20mm size in the primary operation and then to a -20mm all in subbase in the secondary crushing program. The grading of this material is on the fine side of the grading envelope, however, when blended with coarser material such as 50/20 RCA the resultant blend is suitable as an aggregate for the manufacture of concrete, however on close visual inspection see Fig 2 this material is highly contaminated with topsoil, wood, paper, plastic and ceramics. This material was considered not suitable for the research project.

Fig 2: -20mm RCA subbase from Cockburn Recycling facility

Particle size distribution

MATERIAL: BRAJKOVICH R -20MM RECYCLED CONCRETE AGGREGATE(SUBBASE)

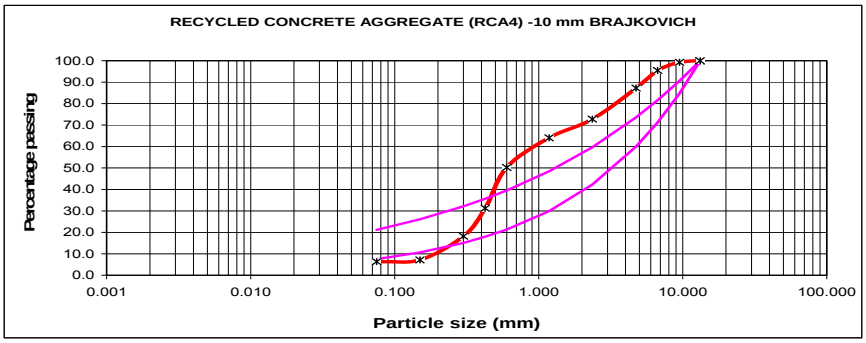
TEST SAMPLE: RCA4

Nominal size mm 13.2

Sieve (mm)		Mass (g)	% retained	% passing
13.20		0	0.0	100.0
13.20		0	0.0	100.0
13.20		0	0.0	100.0
13.20		0	0.0	100.0
9.50		1.21	0.7	99.3
6.70		6.29	3.9	95.4
4.750		13.29	8.2	87.2
2.36		23.59	14.5	72.8
1.18		14.19	8.7	64.1
0.6		22.45	13.8	50.3
0.425		31.09	19.1	31.2
0.3		21.19	13.0	18.2
0.15		18.03	11.1	7.2
0.075		1.26	0.8	6.4
pan		10.45	6.4	

Total Mass (g) = 163.04

top env	bot env
100.00	100
100.00	100.00
100.00	100.00
100.00	100.00
90.60	84.83
81.59	71.24
73.59	59.99
59.66	42.28
48.46	29.90
39.56	21.32
35.67	17.94
32.13	15.08
26.10	10.66
21.20	7.54



The -50mm + 20mm coarse aggregate (50/20 RCA) shown in Fig 3 was examined and was seen to be free of the majority of deleterious contaminants of the -20mm subbase. For the purpose of this research and in order to obtain an aggregate suitable for the manufacturing of geopolymer concrete, it was decided to secondary crush this 50/20 RCA aggregate at Curtin University Department of Civil Engineering.

The first step was to crush this material in a laboratory jaw crusher. The department of Geology at Curtin University gave permission for the use of their Sturtevant laboratory jaw crusher for this purpose (Figure 4.)

Fig 3: -50mm +20mm RCA from Cockburn Recycling facility

Figure 4: Jaw crusher showing jaws

Figure 5: impact crusher showing impeller

The second step was to build an impact crusher (Figure 5) for the purpose of crushing the -50mm +20mm RCA (50/20 RCA) to change the shape of the material from an angular shape, typical of a jaw crusher, to a more a cubical form, a characteristic of an impact crusher. This is more conducive to concrete manufacturing as the cubicle shape reduces the amount of binder required. In addition, by secondary crushing the 50/20 RCA through the impact crusher and taking gradings after each pass it would show the degree of crushing each pass would have. This could be used to design an aggregate with a specific grading in mind and enable it to be tailor made to blend with other aggregates such as the bottom ash and foundry sand.

A small impact industrial crusher was located and purchased (figure 5). As this crusher was previously used for the purpose of crushing glass it was modified with wear liners and blow bars that could be adjusted to increase or decrease the gap and in so doing change the nominal size of the material being crushed.

A catchment bin was installed underneath and was sealed in order to prevent any of the material from escaping. All the voids and openings were sealed with a silicon membrane. A lid was fitted and a chute was installed to feed the material into the crusher to avoid any material from escaping.

Samples were selected, dried in the oven for 24 hrs before crushing. The aggregate was fed into the crusher, collected and then taken to the Geotechnical laboratory for gradings to be undertaken.

The crushing program is shown in Table 3:

Table 3: Crushing program and codes

SAMPLE CODE	INITIAL FEED SIZE	JAW FEED CHOKED/UNCHOKED	JAW OPENING MM	JAW CRUSHER PASSES	IMPACT FEED CHOKED/UNCHOKED	IMPACT GAP MM	IMPACT CRUSHER No. OF PASSES
JC1	-50MM +20MM	CHOKED	15	1			
JU1	-50MM +20MM	UNCHOKED	15	1			
JC1 IMU1 CON	-50MM +20MM	CHOKED	15	1	UNCHOKED	10	1
IMU1 CON	-50MM +20MM				UNCHOKED	10	1
IMU2 CON	-50MM +20MM				UNCHOKED	10	2
IMU3 CON	-50MM +20MM				UNCHOKED	10	3
IMU4 CON	-50MM +20MM				UNCHOKED	10	4
IMU5 CON	-50MM +20MM				UNCHOKED	10	5
IMU1 2.36 EX	-50MM +20MM				UNCHOKED	10	1
IMU2 2.36 EX	-50MM +20MM				UNCHOKED	10	2
IMU3 2.36 EX	-50MM +20MM				UNCHOKED	10	3
IMU4 2.36 EX	-50MM +20MM				UNCHOKED	10	4
IMU5 2.36 EX	-50MM +20MM				UNCHOKED	10	5

SYMBOLS

J	JAW CRUSHER
IM	IMPACT CRUSHER
U	UNCHOCKED FEED
C	CHOKED FEED
NUMBER	NUMBER OF TIMES PASSED THROUGH CRUSHER
CON	CONTINOUOS OPERATION THE PREVIOUS CRUSHED SAMPLE IS NOW THE NEW SAMPLE
2.36 EX	AFTER EACH PASS OF CRUSHING THE FINES PASSING 2.36MM SIEVE WERE AXTRACTED FROM THE SAMPLE

The first stage was to determine the most suitable crusher gap or opening and the following range of gaps settings were chosen viz. 20mm, 15mm and 10mm. Samples were selected and initial gradings were undertaken. The samples were then put through both the crushers with each of the gap settings as described previously. The gradings and shape of the stones were then examined after crushing to assess the reduction ratios. On inspection the decision was made to select a jaw gap of 15mm as this created very little fines and the reduction ratio was deemed suitable. The impact crusher trial was done as previously described for the jaw crusher and it was found that the 10mm gave a noticeable reduction ratio with a suitable cubicle particle shape.

The second stage was to crush the samples through the jaw crusher using the 50/20 RCA feedstock but extracting the fines below the 2.36mm as these fines would be replaced by the foundry sand. Samples were crushed in a choked fed and an unchoked fed operation to examine the effect the two methods have on the grading of the material. The choked feed in jaw crushers maximises the crushing and gives the stone a better shape. Gradings were then undertaken in the geotechnical laboratory at Curtin University as can be seen in Figure 7. On inspection the shape of the crushed aggregate was flat and angular which is not ideal as a concrete aggregate as the workability is adversely affected by aggregates exhibiting high flakiness as can be seen in Figure 6.

Figure 6: Jaw crushed sample (1 pass)

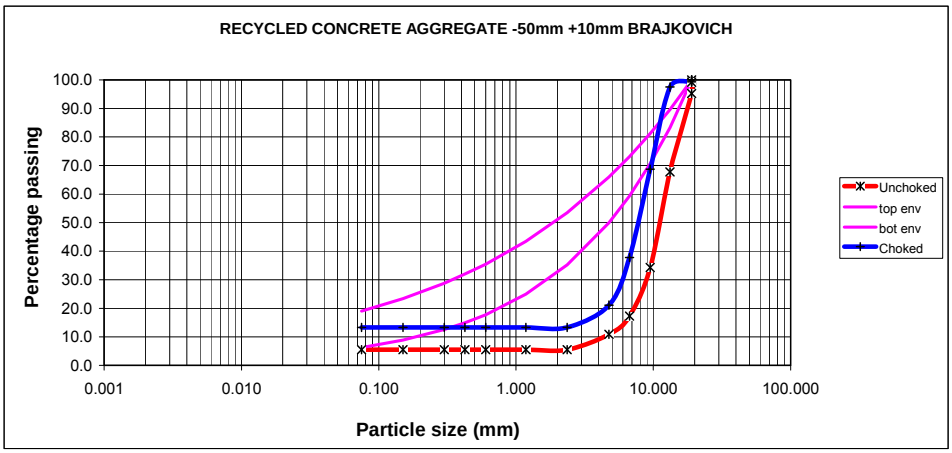
Figure 7: Gradings of a choked and unchoked feed of a jaw crushed sample

Nominal size mm 19.0

				UNCHOKED	CHOKED
Sieve (mm)		Mass (g)	% retained	% passing	% passing
19.0		0	0.0	100.0	100.0
19.0		26	0.8	99.2	100.0
19.0		121	3.9	95.2	99.3
13.20		850	27.5	67.8	97.5
9.50		1035	33.5	34.3	68.7
6.70		527	17.0	17.3	37.8
4.750		198	6.4	10.9	21.1
2.36		167	5.4	5.5	13.3
1.18		0	0.0	5.5	13.3
0.6		0	0.0	5.5	13.3
0.425		0	0.0	5.5	13.3
0.3		0	0.0	5.5	13.3
0.15		0	0.0	5.5	13.3
0.075		0	0.0	5.5	13.3
pan		170	5.5		

Total Mass (g) = 3094

top env	bot env
100.00	100
100.00	100.00
100.00	100.00
89.65	83.35
81.23	70.71
73.15	59.38
65.98	50.00
53.49	35.24
43.44	24.92
35.47	17.77
31.98	14.96
28.81	12.57
23.40	8.89
19.01	6.28



The third stage was to crush samples of the 50/20mm feed size through the jaw as previously done and then take this sample, without disturbance, and pass it through the impact crusher for one pass the result can be seen in Figure 8. Note the change in the shape of the stone in Figure 8 from angular to more cubicle, which is a more desired material for the making of concrete. Gradings were then undertaken. (See Figure 9)

Figure 8: 50/20 RCA crushed 1 pass through jaw and 1 pass through impact crushers with 2.36mm and below extracted

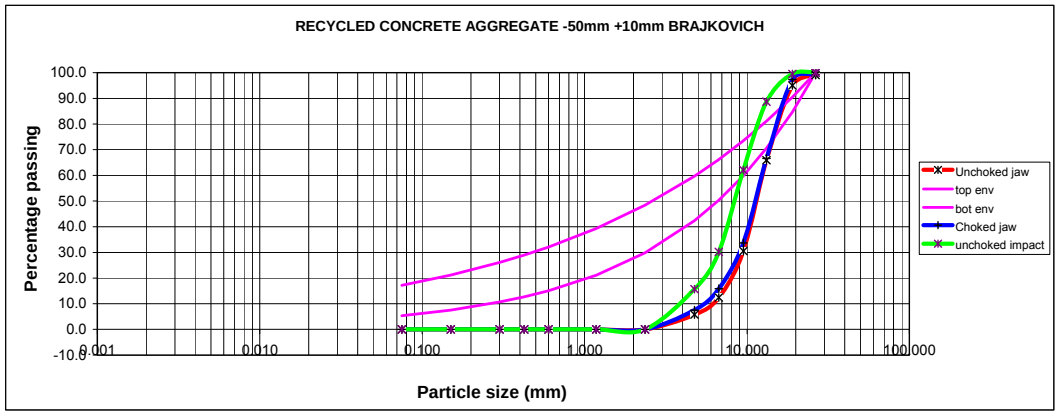
Figure 9: Grading of material with 1pass through jaw and 1 pass through impact crusher (green) compared to 1 pass jaw choked (blue) and 1 pass jaw unchoked (red)

				JAW UNCHOKED	JAW CHOKED	JAW & IMP CHOKED imp
Sieve (mm)		Mass (g)	% retained	% passing	% passing	% passing
26.5		0	0.0	100.0	100.0	100.0
26.5		26	0.9	99.1	99.2	100.0
19.0		121	4.1	95.0	97.3	99.5
13.20		850	29.1	65.9	66.6	88.7
9.50		1035	35.4	30.5	33.7	62.1
6.70		527	18.0	12.5	15.9	30.2
4.750		198	6.8	5.7	7.5	15.7
2.36		167	5.7	0.0	0.0	0.0
1.18		0	0.0	0.0	0.0	0.0
0.6		0	0.0	0.0	0.0	0.0
0.425		0	0.0	0.0	0.0	0.0
0.3		0	0.0	0.0	0.0	0.0
0.15		0	0.0	0.0	0.0	0.0
0.075		0	0.0	0.0	0.0	0.0
pan			0.0			

Total Mass (g) = 2924

Nominal size mm 19.0

top env	bot env
100.00	100
100.00	100.00
90.50	84.67
81.13	70.58
73.51	59.87
66.20	50.28
59.71	42.34
48.41	29.84
39.32	21.10
32.10	15.05
28.94	12.66
26.07	10.64
21.18	7.52
17.20	5.32



The fourth stage was to identify what effect the impact crusher had on the grading, whether one pass was sufficient or a number of passes and if so how many.

Samples were prepared and an initial grading on the feed stock was undertaken for reference purposes. The sample was then put through the impact crusher for one pass. This was then taken to the Geotechnical Laboratory at Curtin and a grading was undertaken to determine the extent of the crushing, the fines content and the shape. This grading was then plotted on a logarithmic graph against the original feed sample and compared. The sample was then put

through the impact crusher for a second pass and then sent for grading and plotting.

The entire sample was then placed for a third, fourth and fifth time and gradings were done and these were plotted. Table 4 shows the grading after each pass for a total of five passes. A sample of the material after 5 passes is shown in Figure 10. The gradings were plotted after each pass to show the extent of crushing as a comparison with the previous pass. See Figure 11.

Figure 10: sample of material after 5 passes through the impact crusher

Table 4: RCA 50/20 feed stock passed through impact crusher 5 times and the grading recorded after each pass

	INITIAL			I X PASS				2 X PASS				3 X PASS				4 X PASS				5 X PASS			
	MASS	%	%	MASS	Mass ret	%	%	MASS	Mass ret	%	%	MASS	Mass ret	%	%	MASS		%	%	MASS		%	%
	RET	RET	PASS	RET	incl -2.36	RET	PASS	RET	incl -2.36	RET	PASS	RET	incl -2.36	RET	PASS	RET		RET	PASS	RET		RET	PASS
Initial sample weight	2293.80																						
Before crush +2.36 weight				2176.30				1854.40				1633.00				1468.50				1341.60			
After crush +2.36 weight				2166.30				1848.50				1627.20				1463.50				1337.90			
Lost during crushing				10.00				5.90				5.80				5.00				3.70			
Sieve size																							
37.5			100.00				100.00				100.00				100.00				100.00				100.00
26.5	212.40	9.26	90.74				100.00				100.00				100.00				100.00				100.00
19	375.40	16.36	74.38	63.90	63.90	2.80	97.20	30.00	30.00	1.32	98.68				100.00				100.00				100.00
13.2	752.40	32.80	41.58	362.20	362.20	15.89	81.31	169.70	169.70	7.46	91.22	99.10	118.70	5.24	94.76	74.30	74.30	3.44	96.56	52.70	52.70	2.34	97.66
9.5	499.60	21.78	19.80	546.60	546.60	23.98	57.33	414.90	414.90	18.24	72.98	339.50	339.50	14.98	79.79	282.10	282.10	13.04	83.52	219.70	219.70	9.74	87.92
6.7	282.10	12.30	7.51	451.90	451.90	19.82	37.51	471.00	471.00	20.71	52.27	422.00	422.00	18.62	61.17	298.30	298.30	13.79	69.73	389.40	389.40	17.27	70.65
4.75	39.30	1.71	5.79	221.60	221.60	9.72	27.79	270.00	270.00	11.87	40.40	284.30	284.30	12.54	48.63	270.30	270.30	12.50	57.23	250.30	250.30	11.10	59.56
2.36	16.00	0.70	5.09	208.20	208.20	9.13	18.66	278.00	278.00	12.22	28.18	304.00	304.00	13.41	35.22	318.50	318.50	14.73	42.50	324.80	324.80	14.40	45.15
Pan before washing	116.90		5.09	308.90				215.20				157.90				120.50				99.20			
Pan after washing	92.30		5.09	291.18				201.12				148.61				113.93				94.68			
1.18	8.21	0.36	4.74	103.77	111.98	4.91	13.74	81.99	193.97	8.53	19.65	64.82	258.79	11.42	23.81	52.50	311.29	14.39	28.11	45.67	356.96	15.83	29.33
0.6	7.61	0.33	4.40	65.93	73.54	3.23	10.52	43.28	116.82	5.14	14.52	31.28	148.10	6.53	17.27	23.09	171.19	7.92	20.19	18.52	189.71	8.41	20.91
0.425	11.42	0.50	3.91	35.26	46.68	2.05	8.47	22.63	69.31	3.05	11.47	15.00	84.31	3.72	13.55	10.81	95.12	4.40	15.79	8.60	103.72	4.60	16.31
0.3	22.06	0.96	2.95	37.32	59.38	2.60	5.86	22.61	81.99	3.60	7.87	15.38	97.37	4.30	9.26	11.06	108.43	5.01	10.78	7.91	116.34	5.16	11.16
0.15	29.15	1.27	1.67	34.56	63.71	2.79	3.07	21.75	85.46	3.76	4.11	15.35	100.81	4.45	4.81	11.50	112.31	5.19	5.59	9.28	121.59	5.39	5.76
0.075	13.46	0.59	1.09	13.35	26.81	1.18	1.89	9.11	35.92	1.58	2.53	6.30	42.22	1.86	2.95	5.04	47.26	2.19	3.40	4.56	51.82	2.30	3.47
Pan	0.36	1.09		0.50	43.18	1.89		0.28	57.54	2.53		0.05	66.88	2.95		0.10	73.55	3.40		0.11	78.18	3.47	
	2294.07	100.00		2162.81	2279.68	100.00		1849.33	2274.61	100.00		1606.37	2266.98	100.00			2162.65	100.00			2255.22	100.00	

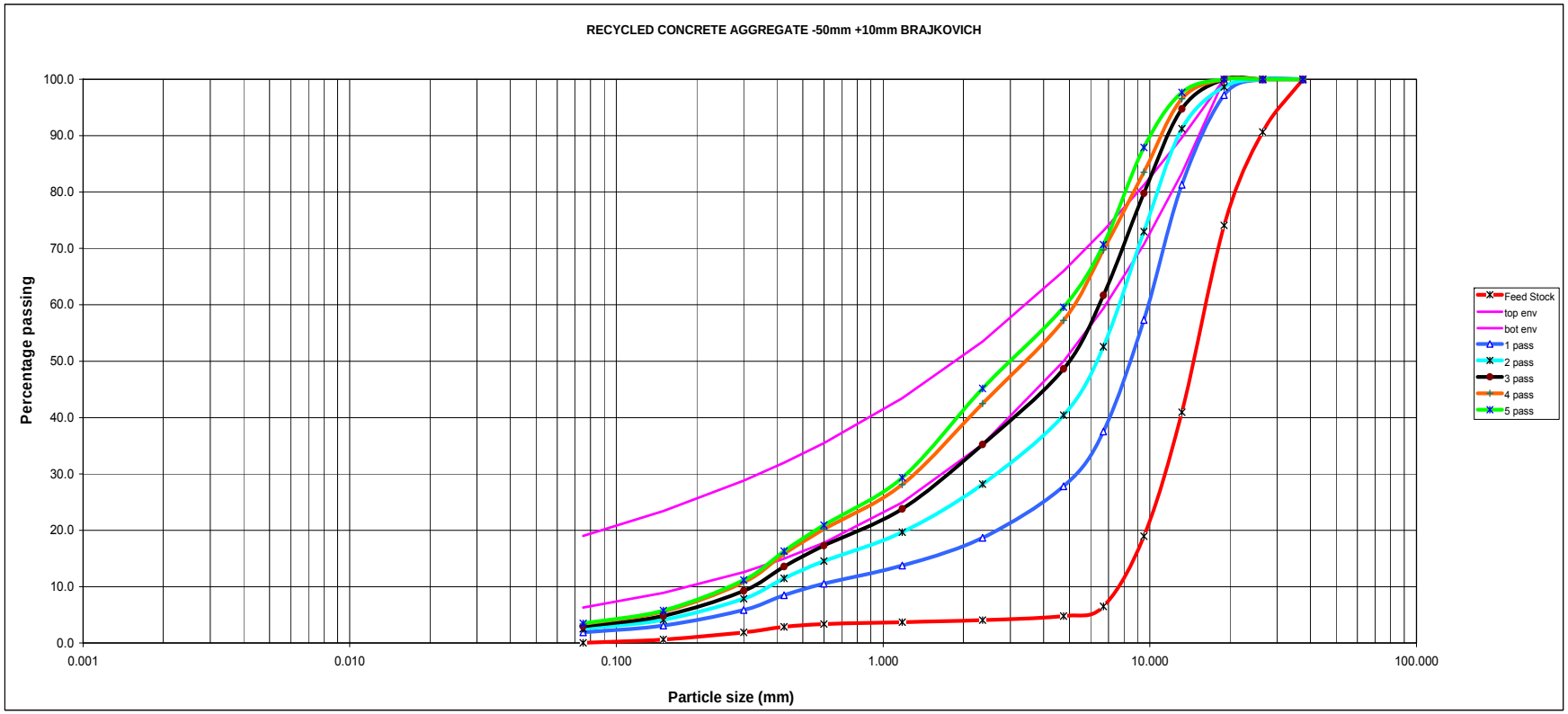
Figure 11: Grading curve showing the comparison of each pass through the impact crusher for up to 5 passes

Nominal size mm 19.0

Sieve (mm)		Mass (g)	% retained	Initial % passing	1 x pass % passing	2 x pass % passing	3 x pass % passing	4 x pass % passing	5 x pass % passing
37.5		0	0.0	100.0	100.0	100.0	100.0	100.0	100.0
26.5		212.4	9.4	90.6	100.0	100.0	100.0	100.0	100.0
19.0		375.4	16.5	74.1	97.2	98.7	100.0	100.0	100.0
13.20		752.4	33.2	40.9	81.3	91.2	94.8	96.6	97.7
9.50		499.6	22.0	18.9	57.3	73.0	79.8	83.5	87.9
6.70		282.1	12.4	6.5	37.5	52.6	61.7	69.7	70.7
4.750		39.3	1.7	4.8	27.8	40.4	48.6	57.2	59.6
2.36		16	0.7	4.1	18.7	28.2	35.2	42.5	45.2
1.18		8.21	0.4	3.7	13.7	19.7	23.8	28.1	29.3
0.6		7.61	0.3	3.4	10.5	14.5	17.3	20.2	20.9
0.425		11.42	0.5	2.9	8.5	11.5	13.6	15.8	16.3
0.3		22.06	1.0	1.9	5.9	7.9	9.3	10.8	11.2
0.15		29.15	1.3	0.6	3.1	4.1	4.8	5.6	5.8
0.075		13.46	0.6	0.0	1.9	2.5	3.0	3.4	3.5
pan		0.36	0.0						

Total Mass (g) = 2269.47

top env	bot env
122.63	140.48787
110.50	118.09898
100.00	100
89.65	83.350875
81.23	70.710678
73.15	59.38279
65.98	50
53.49	35.243514
43.44	24.920928
35.47	17.770466
31.98	14.956076
28.81	12.565617
23.40	8.8852332
19.01	6.2828086



3.2.2 FOUNDRY SAND

Foundry sand has been obtained from Allcast foundry in Kwinana. Allcast is a non-ferrous foundry and the sand type is classed as superfine supplied by Cook Industrial Minerals.

The sand has been mixed with a resin and a catalyst to harden the sand in the mould forming, sand casting process. The sand samples consist of large clumps which are pink and black in colour, mainly from the chemicals and the casting process. See Figure 12.

Figure 12: Foundry sand

The samples were prepared by crushing with a mallet to smaller sizes of approximately 10mm in diameter. The sand was then further crushed and ground in a mortar and pestle to break up all the bonds between the resin and

the sand. This ensured that no sand grains remained bonded together by resin which would have a weakening effect on the geopolymer concrete matrix and thereby influence the final strength of the geopolymer concrete.

Metal fragments were the only visible contaminants and were minimal; however they were removed by hand.

Once this process had been completed, a grading was undertaken of the foundry sand and is shown in Figure 13.

What we can notice is that the majority of the sand particles lie between the 425μm and 150μm sieves depicted by the steep downward trend of the grading curve. If we compare it to a natural fine sand such as Baldavis sand (Figure 13)(grading courtesy of Rocla) we see that there is not a vast difference, which confirms the possibility that this sand can be used as a fine aggregate in making geopolymer concrete.

3.2.3 BOTTOM ASH

The bottom ash used in this research was sampled from Verve Energy's Kwinana Power Station landfill site at Perron quarry. The ash is crystalline and has a few large clumps; however the rest is of a continuous grading but very fine. Bottom ash is black in colour and looks like the parent coal it originally came from.

Figure 14 shows a sample of bottom ash as it comes from the landfill site. The large lumps are not in abundance and are easily removed by hand. Figure 15 shows the grading taken on a sample of bottom ash.

What is noticeable is that the material is light in weight and an abundance of voids are visible which concludes that this is a lightweight material and a very porous one too. (Andrade, Rocha, and Cheriaf 2009)

Figure 13: Grading comparison of foundry sand and Baldivis fine sand

Nominal size mm 2.36

Sieve (mm)		Mass (g)	% retained	FS4 % passing	Rocla % passing
2.36		0	0.0	100.0	100.0
2.36		0	0.0	100.0	100.0
2.36		0	0.0	100.0	100.0
2.36		0	0.0	100.0	100.0
2.36		0	0.0	100.0	100.0
2.36		0	0.0	100.0	100.0
2.36		0	0.0	100.0	100.0
2.36		0	0.0	100.0	100.0
1.18		0.04	0.1	99.9	100.0
0.6		0.14	0.2	99.7	83.0
0.425		2.74	3.9	95.9	54.0
0.3		23.42	33.1	62.8	23.0
0.15		41.41	58.5	4.3	2.0
0.075		0.13	0.2	4.1	1.0
pan		2.88	4.1		

Total Mass (g) = 70.76

top env	bot env
100.00	100
100.00	100.00
100.00	100.00
100.00	100.00
100.00	100.00
100.00	100.00
100.00	100.00
100.00	100.00
81.23	70.71
66.31	50.42
59.79	42.44
53.86	35.65
43.75	25.21
35.53	17.83

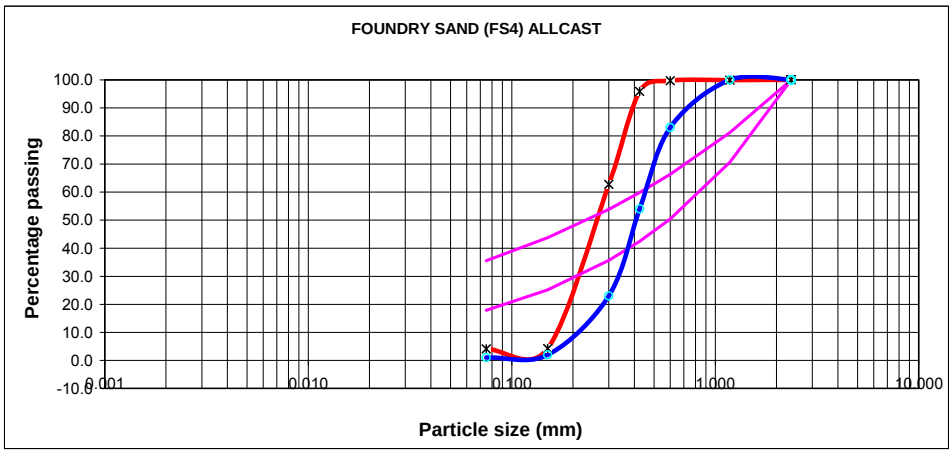


Figure 14: Bottom ash sample from Kwinana Power Station

Five samples were selected and sent for X-ray fluorescence (XRF) analysis at Ultra Trace Laboratories in Canningvale, Perth. Table 5 shows the oxides present and their percentages by weight.

Upon analysis of the XRF data there are two important results that need further mentioning:

Firstly the SiO_2/ $Al2O_3$ by mass of the sample is 58.5% which is less than what has been prescribed as suitable for making geopolymer concrete. Prescribed amount of alumino-silicate oxides should be between 70% to 80% (Hardjito and Rangan 2005) for a satisfactory dissolution to take place, however, it still can be used as has been demonstrated by research done on fluidized bed combustion

bottom ash with the same SiO_2/ $Al2O_3$ ratio of 58%. (Slavik et al. 2008) However in the aforementioned research, the bottom ash played the role of the source material of alumino-silicates. In this scenario the bottom ash would have to be ground if it was to also be a source of alumino-silicates to a particle size below 10 µm.(Slavik et al. 2008)

Table 5: XRF analysis of bottom ash from Kwinana Power Station

OXIDES	BOTTOM ASH SAMPLE 1	BOTTOM ASH SAMPLE 2	BOTTOM ASH SAMPLE 3	BOTTOM ASH SAMPLE 4	BOTTOM ASH SAMPLE 5
	%	%	%	%	%
SiO_2	47.2	47.6	48.9	48.9	48.9
Al_2O_3	11.3	11.5	11.4	11.4	11.4
CaO	2.36	2.18	2.42	2.43	2.41
Fe_2O_3	13.4	13	13.1	13.1	13.2
K_2O	0.41	0.4	0.41	0.42	0.42
MgO	0.64	0.65	0.65	0.66	0.65
Na_2O	0.19	0.17	0.18	0.18	0.18
P_2O_5	0.542	0.535	0.544	0.547	0.544
SO_3	0.08	0.17	0.21	0.21	0.21
TiO_2	0.82	0.83	0.83	0.83	0.85
MnO	0.06	0.05	0.05	0.06	0.05
ZrO_2	0.05	0.05	0.06	0.06	0.06
$Cr2O_3$	0.026	0.018	0.013	0.014	0.014
LOI	21.9	21.9	20.2	20.1	20.1

As the bottom ash in this research is for the purpose of an aggregate first and foremost it is believed that it could also have the added benefit of assisting in providing alumino-silicates to react with the activator to form polymer bonds.

The second factor that can identified from the XRF analysis is the high LOI value, or Loss of Ignition. This occurs when the burning of the coal is inefficient and some coal remains uncombusted. The average LOI is approximately 21% is regarded as high. The parameters suggested are in the order of 5% or less as reported by (Fernández-Jiménez and Palomo 2003). In other research undertaken with bottom ash in geopolymer concrete as well as OPC concrete the LOI has been in the 7.5% and 4.6% range respectively.(Slavik et al. 2008; Andrade, Rocha, and Cheriaf 2009).

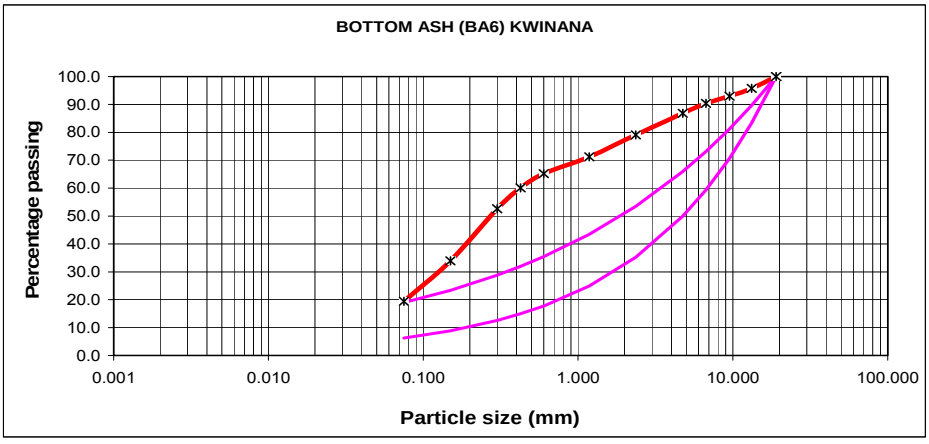
Figure15: Grading of bottom ash from Kwinana Power Station

Nominal size mm 19

Sieve (mm)		Mass (g)	% retained	% passing
19.0		0	0.0	100.0
19.0		0	0.0	100.0
19.0		0	0.0	100.0
13.20		17.9	4.2	95.8
9.50		12	2.8	92.9
6.70		10.6	2.5	90.4
4.750		15.2	3.6	86.8
2.36		32.6	7.7	79.1
1.18		32.9	7.8	71.3
0.6		25.5	6.0	65.2
0.425		21.7	5.1	60.1
0.3		31.5	7.5	52.6
0.15		78.8	18.7	33.9
0.075		61.2	14.5	19.4
pan		81.9	19.4	

Total Mass (g) = 421.8

top env	bot env
100.00	100
100.00	100.00
100.00	100.00
89.65	83.35
81.23	70.71
73.15	59.38
65.98	50.00
53.49	35.24
43.44	24.92
35.47	17.77
31.98	14.96
28.81	12.57
23.40	8.89
19.01	6.28



3.2.4 FLY ASH

Sampling of the fly as was undertaken at Verve Energy's Kwinana Power Station landfill site at Perron Quarry.

4 Samples of the fly ash were sent to Ultra Trace Laboratories in Canningvale, Perth for X-Ray fluorescence (XRF) analysis. Table 6 shows the oxides present and their percentages by weight.

Kwinana fly ash is classed as a low calcium, Class F fly ash. The fly meets the ASTM C618 specification for Class F as the SiO_2 +Al2O_3 + Fe_2O_3 exceeds the minimum requirement of 70% with a combined mass of 82.7%. The ASTM C618 specification requires the Loss of Ignition (LOI) to be less than 6%, GC1(Hardjito and Rangan 2005; Kovalchuk, Fernández-Jiménez, and Palomo 2007) prescribe the LOI to be at an upper limit of 5%.

The colour of the fly ash is a light grey with a yellowish beige tinge. See Figure 16. The sample has lumps present which are easily broken down. The feel is very fine but with hard particles, identified as the carbon or LOI.

In Figure 17 a particle size distribution or grading of the fly as was done by CSIRO at Curtin University using a Malvern Instruments Mastersizer MS 2000. Figure 18 shows a photographic image of the particles under scanning electron Microscope (SEM).

Figure 16: Fly ash sample from Kwinana Power Station

Table 6: XRF analysis of fly ash from Kwinana Power Station

OXIDES	FLY ASH SAMPLE 1	FLY ASH SAMPLE 2	FLY ASH SAMPLE 3	FLY ASH SAMPLE 4
	%	%	%	%
SiO_2	48.3	49	48	48
Al_2O_3	22.5	21.9	22.9	23
CaO	1.7	1.72	1.73	1.72
Fe_2O_3	11.6	12.1	11.8	11.8
K_2O	0.59	0.59	0.59	0.6
MgO	0.79	0.79	0.79	0.79
Na_2O	0.37	0.34	0.37	0.36
P_2O_5	1.6	1.58	1.67	1.66
SO_3	0.09	0.07	0.06	0.05
TiO_2	1.27	1.28	1.28	1.28
MnO	0.09	0.09	0.09	0.09
ZrO_2	0.06	0.06	0.06	0.06
$Cr2O_3$	0.024	0.049	0.043	0.034
LOI	9.76	9.36	9.35	9.39

Figure 17: Grading of Kwinana fly ash using Malvern Mastersizer MS 2000

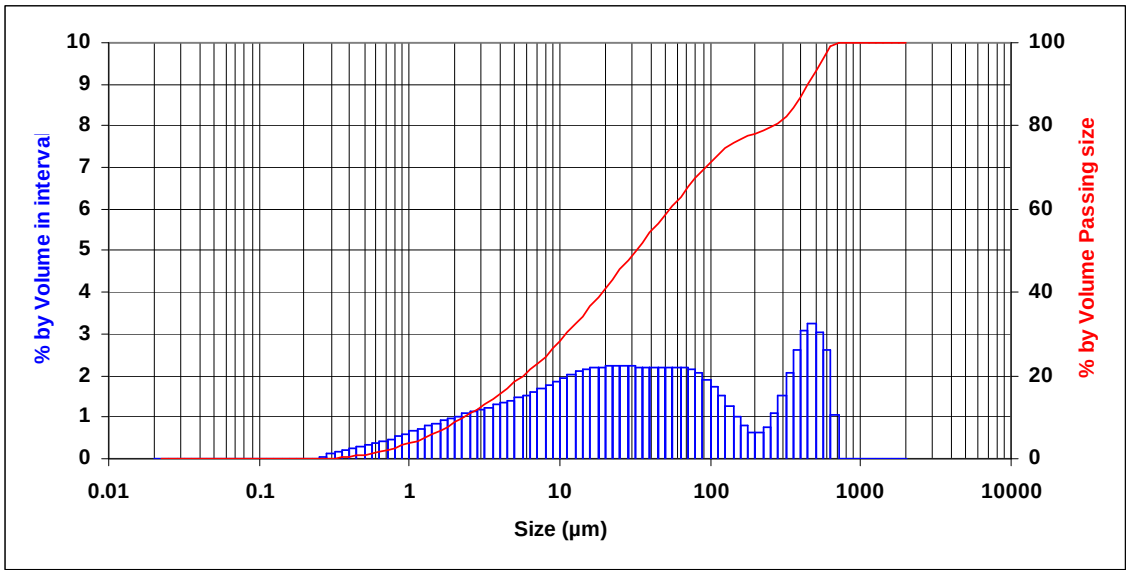
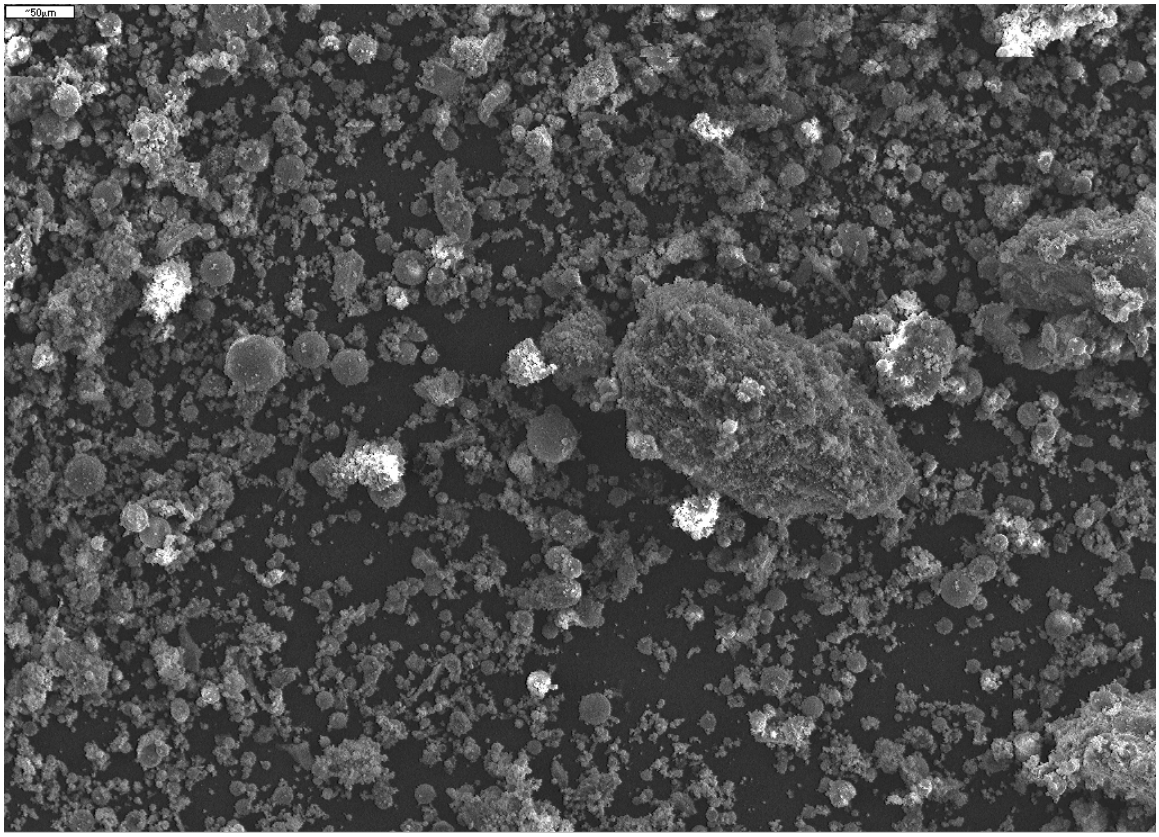


Figure 18: Photograph of Kwinana fly ash with scanning electron microscope



What is noticeable from the psd grading curve is that there is a very definite secondary “hump” between 150 μm and 700 μm which represents the LOI fraction. All the fly ash particles are between 0.2 μm and 150 μm which is normal for fly ash.

From the electron microscope image in Figure 18, the small spherical balls seen are the fly ash particles; this spherical shape is what makes fly ash a useful addition to concrete mixes for improving workability. The large angular particle right of centre in Figure 18 is unburnt coal or LOI and it is these particles that feature in the psd grading curve between 150 μm and 700 μm.

The fly ash is prepared by drying in an oven for 24 hrs and then reducing the lumps using a mortar and pestle until a stage is reached where there is no cohesiveness between the particles. The fly ash is now ready for use in making geopolymer concrete.

3.2.5 SODIUM HYDROXIDE

The sodium hydroxide is extremely alkaline and care in handling this chemical has to be taken.

Sodium Hydroxide can be in two forms viz. the pellet form of 97% purity or the pre-diluted for of 50/50 dilution by mass.

For this research a commercial grade of 97% purity supplied by Lomb Scientific was diluted in water to obtain a concentration of 8 Molar. GC1(Hardjito and Rangan 2005) mix design was followed where an 8M concentration amounts to 320 grams of NaOH solids per litre of water or 262 grams per kg of solution at 8M concentration.

3.2.6 SODIUM SILICATE

Sodium silicate is also known as water glass and has a relatively high viscosity. The sodium silicate solution was obtained from PQ Australia and is a known as Vitrosol D – A53 or Type 'D". The compositions supplied by PQ Australia are as follows:

	Typical 'D'	Sample 1	Sample 2	April Drum	May Drum	June Drum
Na_2O%	14.64	14.49	14.58	14.76	14.59	15.05
SiO_2%	29.46	29.4	29.39	29.76	30.48	29.08
Solids%	44.10	43.89	43.97	44.52	45.07	44.13
Ratio (SiO_2/Na_2O)	2.01	2.03	2.02	2.02	2.09	1.93
Viscosity @20^oC (cps)	345	347	358	427	492	458

3.2.7 SUPERPLASTICISER

The superplasticiser used was Rheobuild 100 which is a sulphonate polymer. This plasticizer is a high water replacement plasticizer and is brown in colour. Superplasticiser can be used up to 4 % but the increase in the plasticizer means and increase in cost. GC1(Hardjito and Rangan 2005) proposes an amount equal to 1.5% of the mass of the fly ash.

3.3 MIX DESIGN

3.3.1 BLENDING OF AGGREGATES

3.3.1.1 INTRODUCTION

In theory if the aggregate grading falls within, or for that matter, follows the maximum density envelope described by the equation $p=100(d/D)^{\wedge n}$ where d is the sieve in question, D is the nominal size of the aggregate and n=0.3 for the uppermost limit, n=0.45 for the lower limit.

This maximum density envelope is the target range of where the aggregates grading fall within. In most cases aggregates, whether fine or coarse, do not have a full range of particles allowing them to fall within this envelope and for this reason they need to be blended with other aggregates in certain proportions to make up the deficiency. The resultant aggregate grading should fall within this envelope if the deficient individual aggregates are blended together correctly.

The driver behind aiming at a grading within the maximum density envelope is for the packing of the particles to be at an optimum so that the voids between the bigger particles are filled with smaller particles and so on.

Once this has been achieved then the cement or geopolymer binder required to bind the particles together is at a minimum. This has an economical benefit as well because the cement/binder is the most costly item in the manufacturing of concrete.

3.3.2 METHODS OF BLENDING AGGREGATES

A.M. Neville's book Properties of concrete (Neville 1995) provides two methods for determining the blended aggregate proportions i.e. a mathematical or calculation or a graphical method. These methods have their limitations with regard to a number of coarse and fine aggregates being blended as they only really take into account the percentage passing two sieves.

With computers today software has been written to do this across all the sieve sizes. At first the blending was done using software created by Luboš Svoboda of the University of Prague, Czech Republic called AGGMIX (Svoboda 2007) which can blend up to 9 aggregates by calculating proportions at each sieve size by a mathematical algorithm and then producing a resultant grading curve. The

software was originally written in Czech and is not a windows based so the application is difficult to understand and cumbersome to work with.

Software based on a similar algorithm from J. Hoggard (Hoggard 1999) is a windows based program which operates on Microsoft Excel.

Both programs were compared by inputting the same data. The results were almost exact, the only difference being is that the Aggmix program runs on US sieve sizes whereas Hoggard's program uses AS/NZ Standard sieve sizes.

3.3.3 BLENDING REGIME

A blending regime was structured around using the different RCA crushed samples and codes as described in Table 3 The change is that sample IMU5 CON was set aside as the grading is similar to that to that of IMU4 CON and as this was to be blended with bottom ash and foundry sand, which have fine gradings, this would cause a duplication so IMU5 CON has been left out.

Each type of RCA crushed aggregate was blended in proportions of 50%, 60% and 70% by mass with varying combinations of bottom ash and foundry sand.

Table 7 gives the breakdown of the 75 blends undertaken. Appendix A provides graphical solutions of the psd grading of the blended materials. One of the aims of this research was to investigate if the RCA, bottom ash and foundry sand can be used to make geopolymer concrete.

From the gradings three blends were selected based on the blended grading falling within the target grading envelope. Other gradings were possibly more "perfect" but they were the ones without the foundry sand and were considered not in line with the aims of this research. The chosen blends were follows:

Table 7: List of aggregate blends

	JC1 IMU1 CON		
	RCA	%	50
Blend	BA %	FS %	JC1 IMU1 %
1	0	50	50
2	10	40	50
3	20	30	50
4	30	20	50
5	40	10	50
6	50	0	50

	IMU1 CON		
	RCA	%	50
Blend	BA %	FS %	IMU1 CON %
16	0	50	50
17	10	40	50
18	20	30	50
19	30	20	50
20	40	10	50
21	50	0	50

	IMU2 CON		
	RCA	%	50
Blend	BA %	FS %	IMU2 CON %
31	0	50	50
32	10	40	50
33	20	30	50
34	30	20	50
35	40	10	50
36	50	0	50

	IMU3 CON		
	RCA	%	50
Blend	BA %	FS %	IMU3 CON %
46	0	50	50
47	10	40	50
48	20	30	50
49	30	20	50
50	40	10	50
51	50	0	50

	IMU4 CON		
	RCA	%	50
Blend	BA %	FS %	IMU4 CON %
61	0	50	50
62	10	40	50
63	20	30	50
64	30	20	50
65	40	10	50
66	50	0	50

	JC1 IMU1 CON		
	RCA	%	60
Blend	BA %	FS %	JC1 IMU1 %
7	0	40	60
8	10	30	60
9	20	20	60
10	30	10	60
11	40	0	60

	IMU1 CON		
	RCA	%	60
Blend	BA %	FS %	IMU1 CON %
22	0	40	60
23	10	30	60
24	20	20	60
25	30	10	60
26	40	0	60

	IMU2 CON		
	RCA	%	60
Blend	BA %	FS %	IMU2 CON %
37	0	40	60
38	10	30	60
39	20	20	60
40	30	10	60
41	40	0	60

	IMU3 CON		
	RCA	%	60
Blend	BA %	FS %	IMU3 CON %
52	0	40	60
53	10	30	60
54	20	20	60
55	30	10	60
56	40	0	60

	IMU4 CON		
	RCA	%	60
Blend	BA %	FS %	IMU4 CON %
67	0	40	60
68	10	30	60
69	20	20	60
70	30	10	60
71	40	0	60

	JC1 IMU1 CON		
	RCA	%	70
Blend	BA %	FS %	JC1 IMU1 %
12	0	30	70
13	10	20	70
14	20	10	70
15	30	0	70

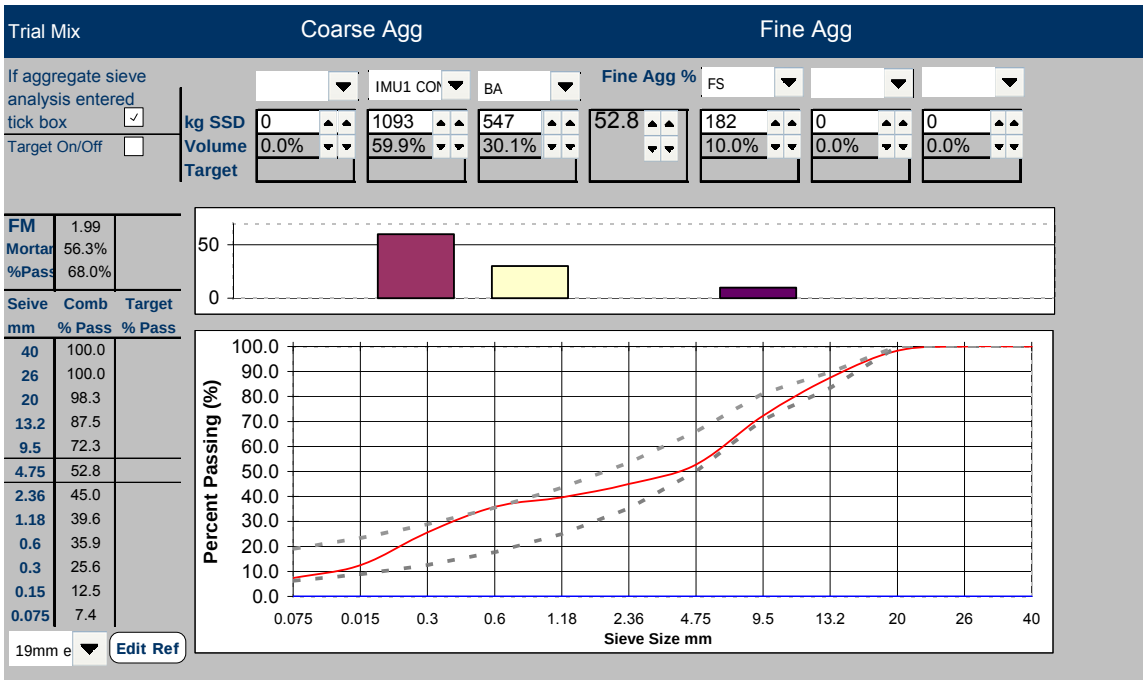
	IMU1 CON		
	RCA	%	70
Blend	BA %	FS %	IMU1 CON %
27	0	30	70
28	10	20	70
29	20	10	70
30	30	0	70

	IMU2 CON		
	RCA	%	70
Blend	BA %	FS %	IMU2 CON %
42	0	30	70
43	10	20	70
44	20	10	70
45	30	0	70

	IMU3 CON		
	RCA	%	70
Blend	BA %	FS %	IMU3 CON %
57	0	30	70
58	10	20	70
59	20	10	70
60	30	0	70

	IMU4 CON		
	RCA	%	70
Blend	BA %	FS %	IMU4 CON %
72	0	30	70
73	10	20	70
74	20	10	70
75	30	0	70

- **Figure 19: Blend 25**: 60 % RCA (IMU1 COM), 30% (BA) bottom ash and 10% (FS) foundry sand



- **Figure 20: Blend 28**: 70 % RCA (IMU1 COM), 10% (BA) bottom ash and 20% (FS) foundry Sand

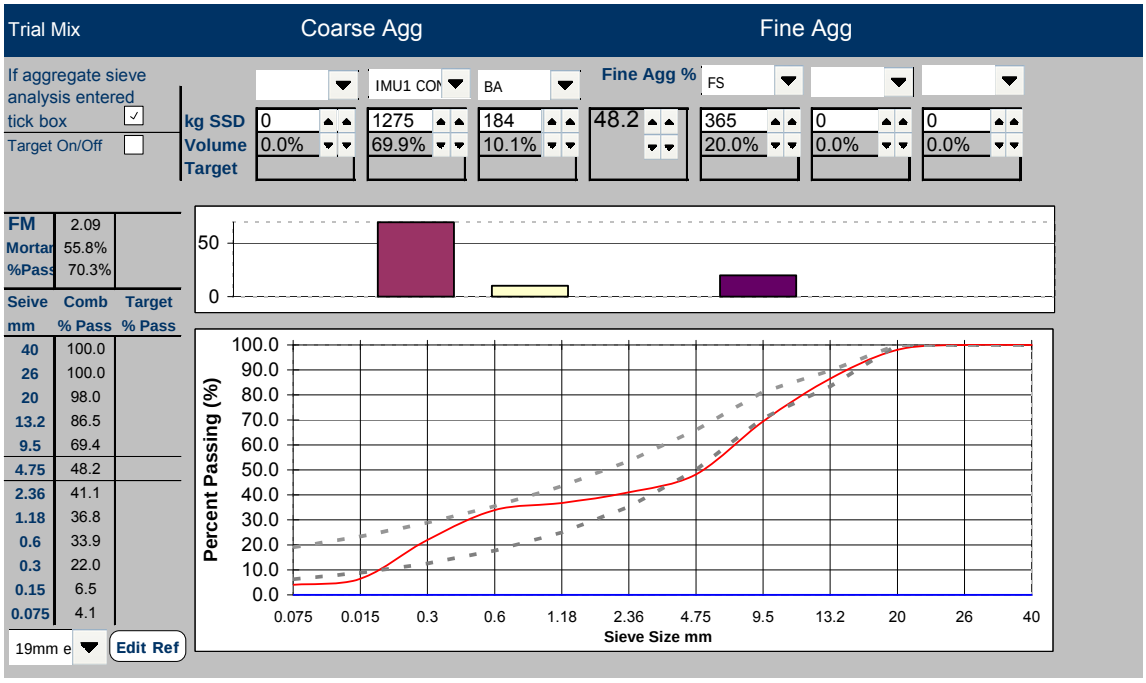
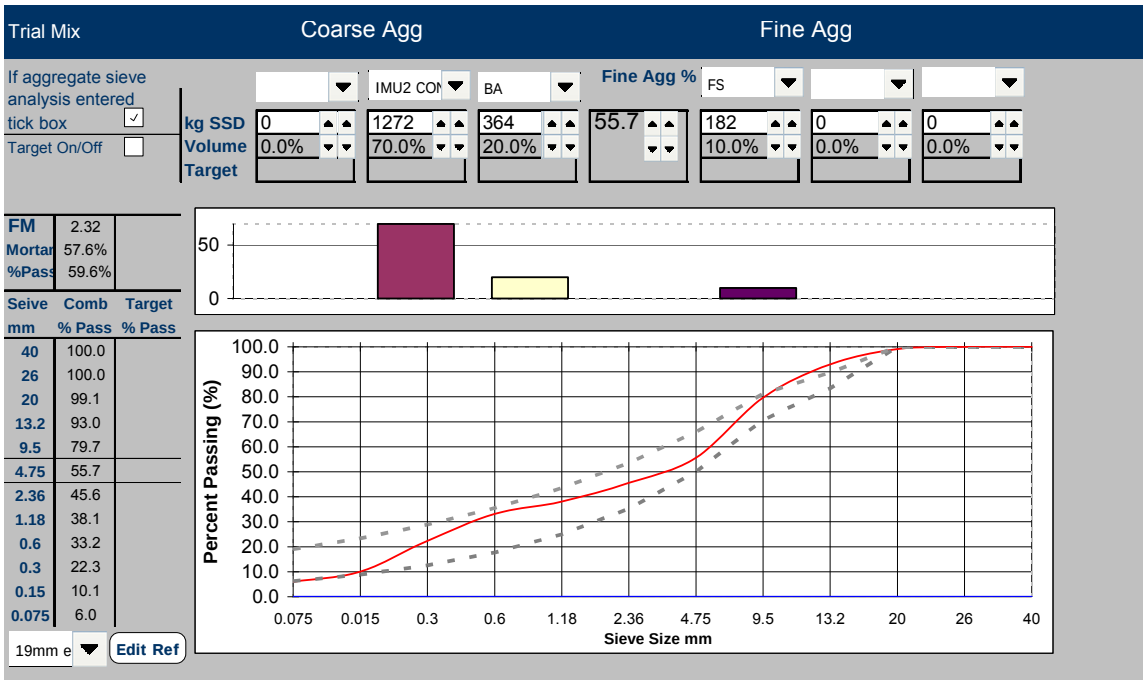


Figure 21: Blend 44: 70 % RCA (IMU2 COM), 20% (BA) bottom ash and 10% (FS) foundry Sand



3.4 MIX DESIGN CALCULATIONS

As mentioned the mix design will be according to GC1, low calcium fly ash geopolymer concrete by Hardjito and Rangan.(Hardjito and Rangan 2005).

The mix design is aimed at the concrete masonry units (Figure 22), primarily used in retaining wall structures where the specification (Standards Australia 2008) is between 2.5MPA and 5 MPA. This also would allow us to use the 19mm nominal size aggregate.

Figure 22: Concrete masonry units

As there is very little research and literature involving low specification geopolymer concrete a geopolymer mix of known strength was used. This mix using natural aggregates and natural sand produced geopolymer concrete of strength 45MPa. What was unknown was what resultant strength would a mixture of recycled concrete aggregate, bottom ash and foundry sand achieve using recycled materials using this known mix design.

The concentration of the sodium Hydroxide was taken at 8 Molar as set out in GC1. (Hardjito and Rangan 2005).

Precast masonry products are cast in such a manner that they are demoulded immediately and therefore require a dry mix i.e. a mix with zero slump.

The water to geopolymer solids ratio (w/gps) is an important factor in determining the slump of the concrete. The fact that recycled concrete aggregate and bottom ash are more porous than natural aggregates (Standards Australia 2002; Andrade, Rocha, and Cheriaf 2009) the w/gps listed in GC1 (Hardjito and Rangan 2005) gives an indication of the workability and in particular the slump of various mixes for certain w/gps ratios. As the materials are distinctly different compared with those of natural aggregates it was necessary to batch mixes on each of the three design blends at the w/gps ratios prescribed in GC1(Hardjito and Rangan 2005) to observe and record any similarities or differences. In particular which w/gps would deliver the best mix design for use in making masonry units. Mixes were designed for the following water to geopolymer solid ratios (w/gps):

- Very stiff w/gps = 0.16
- Stiff w/gps = 0.18
- Moderate w/gps = 0.20
- High w/gps = 0.22
- Very high w/gps = 0.24

Mix design Water to Geopolymer ratio (w/gps) = 0.16

As the mix design is based on 8 molar concentration of sodium hydroxide (NaOH) and sodium silicate (premixed in drum form) this design there has no added water and therefore no water is able to be subtracted form the mix. The next w/gps mix design is a stiff mix at w/gps of 0.18 which also uses no additional water. This means that this mix with the mix design at 8 Molar can not be produced under the parameters of this research.

Table 8: Mix design Water to Geopolymer ratio (w/gps) = 0.18

	UNIT	QUANT		
Assumption of normal weight of concrete	kg/m3	2400		1
Assume recycled concrete weight reduction	%	10%		2
Calculated weight of recycled concrete	kg/m3	2160	1x2=	3
Assume combined aggregates proportion of total weight	%	77%		4
Calculated weight of recycled aggregates	kg/m3	1663	3x4=	5
Mass of fly ash and alkaline liquid	kg/m3	497	3-5=	6
Assume alkaline liquid to fly ash ratio as		0.35		7
Mass of fly ash	**kg/m3**	**368**	**6/(1+7)=**	**8**
Mass of alkaline liquid	kg/m3	129	6-8=	9
Assume ratio of sodium silicate to sodium hydroxide by mass as		2.5		10
Mass of sodium hydroxide solution	**kg/m3**	**37**	**9/(1+10)=**	**11**
Mass of sodium silicate solution	**kg/m3**	**92**	**9-11=**	**12**

Water to geopolymer solids calculation

Sodium silicate solution A53

Water percentage	%	55.9%		13
Silicate solids Na2O & Si2O4 percentage	%	44.1%	100-13=	14
Mass of water in Silicate solution	kg/m3	51.43	13*12=	15
Mass of silicate solids	kg/m3	40.57	14*12=	16

Sodium Hydroxide Solution NaOH

Solution concentration	M	8		17
Sodium Hydroxide Solids NaOH percentage	%	26.2%		18
Water percentage	%	73.8%	100-18=	19
Mass of Hydroxide Solids	kg/m3	9.64	18*11=	20
Mass of water in hydroxide solution	kg/m3	27.16	19*11=	21

Total mass of water

Mass of water silicate solution	kg/m3	51.43		15
Mass of water Hydroxide solution	kg/m3	27.16		21
Added water to increase slump and W/GPS ratio	kg/m3			
Total mass of water	**kg/m3**	**78.59**	15+21=	22

Total mass of geopolymer solids

Mass of fly ash	kg/m3	368		8
Mass of silicate solids	kg/m3	40.57		16
Mass of Hydroxide Solids	kg/m3	9.64		20
Total mass of geopolymer solids	**kg/m3**	**418.21**	8+16+20=	23

Water to geopolymer solids ratio W/GPS	**0.18791**

BATCH QUANTITY CALCULATION

No. of cylinders	**12**
Cylinder size: dia=100mm, height=200mm	
BATCH SIZE M3=	**0.0188571**

		BATCH QUANT	BATCH QUANT INCL WASTE
TOTAL WEIGHT OF AGGREGATES at SSD	grams	31363.20	34499.52
FLY ASH	grams	6939.43	7633.37
HYDROXIDE (NaOH)	grams	693.94	763.34
SILICATE	grams	1734.86	1908.34
ADDED WATER to increase w/gps ratio (slump)	grams	0.00	0.00
SUPERPLASTICIZER @1.5%mass of fly ash	grams	104.09	114.50

Table 9: Mix design Water to Geopolymer ratio (w/gps) = 0.20

	UNIT	QUANT		
Assumption of normal weight of concrete	kg/m3	2400		1
Assume recycled concrete weight reduction	%	10%		2
Calculated weight of recycled concrete	kg/m3	2160	1x2=	3
Assume combined aggregates proportion of total weight	%	77%		4
Calculated weight of recycled aggregates	kg/m3	1663	3x4=	5
Mass of fly ash and alkaline liquid	kg/m3	497	3-5=	6
Assume alkaline liquid to fly ash ratio as		0.35		7
Mass of fly ash	**kg/m3**	**368**	**6/(1+7)=**	**8**
Mass of alkaline liquid	kg/m3	129	6-8=	9
Assume ratio of sodium silicate to sodium hydroxide by mass as		2.5		10
Mass of sodium hydroxide solution	**kg/m3**	**37**	**9/(1+10)=**	**11**
Mass of sodium silicate solution	**kg/m3**	**92**	**9-11=**	**12**

Water to geopolymer solids calculation

Sodium silicate solution A53

Water percentage	%	55.9%		13
Silicate solids Na2O & Si2O4 percentage	%	44.1%	100-13=	14
Mass of water in Silicate solution	kg/m3	51.43	13*12=	15
Mass of silicate solids	kg/m3	40.57	14*12=	16

Sodium Hydroxide Solution NaOH

Solution concentration	M	8		17
Sodium Hydroxide Solids NaOH percentage	%	26.2%		18
Water percentage	%	73.8%	100-18=	19
Mass of Hydroxide Solids	kg/m3	9.64	18*11=	20
Mass of water in hydroxide solution	kg/m3	27.16	19*11=	21

Total mass of water

Mass of water silicate solution	kg/m3	51.43		15
Mass of water Hydroxide solution	kg/m3	27.16		21
Added water to increase slump and W/GPS ratio	kg/m3	5.20		
Total mass of water	**kg/m3**	**83.79**	15+21=	22

Total mass of geopolymer solids

Mass of fly ash	kg/m3	368		8
Mass of silicate solids	kg/m3	40.57		16
Mass of Hydroxide Solids	kg/m3	9.64		20
Total mass of geopolymer solids	**kg/m3**	**418.21**	8+16+20=	23

Water to geopolymer solids ratio W/GPS	**0.20034**

BATCH QUANTITY CALCULATION

No. of cylinders	**12**
Cylinder size: dia=100mm, height=200mm	
BATCH SIZE M3=	**0.0188571**

		BATCH QUANT	BATCH QUANT INCL WASTE
TOTAL WEIGHT OF AGGREGATES at SSD	grams	31363.20	34499.52
FLY ASH	grams	6939.43	7633.37
HYDROXIDE (NaOH)	grams	693.94	763.34
SILICATE	grams	1734.86	1908.34
ADDED WATER to increase w/gps ratio (slump)	grams	98.06	107.86
SUPERPLASTICIZER @1.5%mass of fly ash	grams	104.09	114.50

Table 10: Mix design Water to Geopolymer (w/gps) = 0.22

	UNIT	QUANT		
Assumption of normal weight of concrete	kg/m3	2400		1
Assume recycled concrete weight reduction	%	10%		2
Calculated weight of recycled concrete	kg/m3	2160	1x2=	3
Assume combined aggregates proportion of total weight	%	77%		4
Calculated weight of recycled aggregates	kg/m3	1663	3x4=	5
Mass of fly ash and alkaline liquid	kg/m3	497	3-5=	6
Assume alkaline liquid to fly ash ratio as		0.35		7
Mass of fly ash	**kg/m3**	**368**	**6/(1+7)=**	**8**
Mass of alkaline liquid	kg/m3	129	6-8=	9
Assume ratio of sodium silicate to sodium hydroxide by mass as		2.5		10
Mass of sodium hydroxide solution	**kg/m3**	**37**	**9/(1+10)=**	**11**
Mass of sodium silicate solution	**kg/m3**	**92**	**9-11=**	**12**

Water to geopolymer solids calculation

Sodium silicate solution A53

Water percentage	%	55.9%		13
Silicate solids Na2O & Si2O4 percentage	%	44.1%	100-13=	14
Mass of water in Silicate solution	kg/m3	51.43	13*12=	15
Mass of silicate solids	kg/m3	40.57	14*12=	16

Sodium Hydroxide Solution NaOH

Solution concentration	M	8		17
Sodium Hydroxide Solids NaOH percentage	%	26.2%		18
Water percentage	%	73.8%	100-18=	19
Mass of Hydroxide Solids	kg/m3	9.64	18*11=	20
Mass of water in hydroxide solution	kg/m3	27.16	19*11=	21

Total mass of water

Mass of water silicate solution	kg/m3	51.43		15
Mass of water Hydroxide solution	kg/m3	27.16		21
Added water to increase slump and W/GPS ratio	kg/m3	13.50		
Total mass of water	**kg/m3**	**92.09**	15+21=	22

Total mass of geopolymer solids

Mass of fly ash	kg/m3	368		8
Mass of silicate solids	kg/m3	40.57		16
Mass of Hydroxide Solids	kg/m3	9.64		20
Total mass of geopolymer solids	**kg/m3**	**418.21**	8+16+20=	23

Water to geopolymer solids ratio W/GPS	**0.22019**

BATCH QUANTITY CALCULATION

No. of cylinders	**12**
Cylinder size: dia=100mm, height=200mm	
BATCH SIZE M3=	**0.0188571**

		BATCH QUANT	BATCH QUANT INCL WASTE
TOTAL WEIGHT OF AGGREGATES at SSD	grams	31363.20	34499.52
FLY ASH	grams	6939.43	7633.37
HYDROXIDE (NaOH)	grams	693.94	763.34
SILICATE	grams	1734.86	1908.34
ADDED WATER to increase w/gps ratio (slump)	grams	254.57	280.03
SUPERPLASTICIZER @1.5%mass of fly ash	grams	104.09	114.50

Table 11: Mix design Water to Geopolymer ratio (w/gps) = 0.24

	UNIT	QUANT		
Assumption of normal weight of concrete	kg/m3	2400		1
Assume recycled concrete weight reduction	%	10%		2
Calculated weight of recycled concrete	kg/m3	2160	1x2=	3
Assume combined aggregates proportion of total weight	%	77%		4
Calculated weight of recycled aggregates	kg/m3	1663	3x4=	5
Mass of fly ash and alkaline liquid	kg/m3	497	3-5=	6
Assume alkaline liquid to fly ash ratio as		0.35		7
Mass of fly ash	**kg/m3**	**368**	**6/(1+7)=**	**8**
Mass of alkaline liquid	kg/m3	129	6-8=	9
Assume ratio of sodium silicate to sodium hydroxide by mass as		2.5		10
Mass of sodium hydroxide solution	**kg/m3**	**37**	**9/(1+10)=**	**11**
Mass of sodium silicate solution	**kg/m3**	**92**	**9-11=**	**12**

Water to geopolymer solids calculation

Sodium silicate solution A53

Water percentage	%	55.9%		13
Silicate solids Na2O & Si2O4 percentage	%	44.1%	100-13=	14
Mass of water in Silicate solution	kg/m3	51.43	13*12=	15
Mass of silicate solids	kg/m3	40.57	14*12=	16

Sodium Hydroxide Solution NaOH

Solution concentration	M	8		17
Sodium Hydroxide Solids NaOH percentage	%	26.2%		18
Water percentage	%	73.8%	100-18=	19
Mass of Hydroxide Solids	kg/m3	9.64	18*11=	20
Mass of water in hydroxide solution	kg/m3	27.16	19*11=	21

Total mass of water

Mass of water silicate solution	kg/m3	51.43		15
Mass of water Hydroxide solution	kg/m3	27.16		21
Added water to increase slump and W/GPS ratio	kg/m3	21.80		
Total mass of water	**kg/m3**	**100.39**	15+21=	22

Total mass of geopolymer solids

Mass of fly ash	kg/m3	368		8
Mass of silicate solids	kg/m3	40.57		16
Mass of Hydroxide Solids	kg/m3	9.64		20
Total mass of geopolymer solids	**kg/m3**	**418.21**	8+16+20=	23

Water to geopolymer solids ratio W/GPS	**0.24004**

BATCH QUANTITY CALCULATION

No. of cylinders	**1**
Cylinder size: dia=100mm, height=200mm	
BATCH SIZE M3=	**0.0015714**

		BATCH QUANT	BATCH QUANT INCL WASTE
TOTAL WEIGHT OF AGGREGATES at SSD	grams	2613.60	2874.96
FLY ASH	grams	578.29	636.11
HYDROXIDE (NaOH)	grams	57.83	63.61
SILICATE	grams	144.57	159.03
ADDED WATER to increase w/gps ratio (slump)	grams	34.26	37.68
SUPERPLASTICIZER @1.5%mass of fly ash	grams	8.67	9.54

3.5 PREPARATION

- The RCA was crushed so that two large samples of approximately 50kg of type codes IMU2 CON and 1 large sample of approximately 25kg IMU1 CON were crushed as shown in Figure 23.

Figure 23: RCA sample prepared for batching

- Bottom ash samples were taken from the sample bags and spread in pans and all the large lumps removed.

- Foundry sand was crushed with a mallet and then ground in a mortar and pestle to a stage that no visible cohesion existed between the particles.

- Fly ash samples were taken from sample bags and crushed with a wooden mallet. The sample was then placed in the oven for 24 hrs to dry. Once oven dried the fly ash was then ground in a mortar and pestle until a consistent texture was achieved. None of the LOI was removed.

- NaOH of strength 8 Molar was prepared in the Chemistry Department at Curtin University two days prior to mixing.

- Sodium silicate was mixed with the NaOH the day before and left to stand for 24 hrs to assist in the polymerization.

- Water and superplasticiser were weighed and placed in containers.

- 12 concrete moulds per batch were sandblasted and cleaned and treated with a water based mould release agent.

- The concrete mixer used was of pan mixer type in the concrete laboratory at Curtin University. All equipment to be used was cleaned prior to use in potable water to rid any trace of Portland cement.

- The aggregates were approximately proportioned into batch quantities according to mix designs and brought to SSD moisture content.

3.6 MIXING AND CASTING

An 80 litre pan mixer was used in the Curtin University concrete laboratory (Figure 24).

First was the RCA aggregate followed by the bottom ash, the foundry sand and the fly ash. The mix was then mixed for three minutes before adding the chemicals. The sodium hydroxide and the sodium silicate and the water, water

was only added in the case of the batches where the water to geopolymer solids were 0.20 and 0.22. In the case of the water to geopolymer solids ratio of 0.18 no additional water was added as sufficient water is in the sodium hydroxide and sodium silicate mixtures.

The mixing of the aggregates and the chemicals continued for four minutes and then mixing was stopped. The mix was placed into the testing moulds in 3 equal layers and tampered with 60 blows per layer for compaction, then vibrated for 10 seconds on a vibrating table.

A slump test was also taken on each batch.

Figure 24: 80 litre pan mixer

Figure 25 Slump test

3.7 CURING

After mixing was complete there was no rest period allowed and the moulds were sealed with plastic and placed in the oven at a preset temperature of 60 degrees Celsius for a period of 24 hours.

Dry curing was chosen over steam curing as previous research has shown that dry curing with a sodium system results in higher compressive strength.(Hardjito and Rangan 2005)

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter the results of the experiments are discussed in terms of the aims of this research, and it is with these aims in mind that we will discuss and evaluate the work.

The experimentation is based on the work of GC1 and the methods set out in GC1. The main aim of this research was to build on the work done in GC1 by using the proven methods to investigate the possibility whether this technology can be applied to a mix where the entire matrix was composed of waste materials. (Hardjito and Rangan 2005)

Concrete masonry products are products where the specification is deemed relatively low and with this in mind it was seen as a viable starting point.

4.2 MIXING

4.2.1 WATER TO GEOPOLYMER SOLIDS RATIO

In terms of developing a mix termed “dry mix” for manufacturing masonry products the decision was taken to experiment across the broad spectrum of known and established water to geopolymer solids ratios (w/gps). Using the known w/gps ratios cited in GC1 these ratios could be used in separate mix designs with each of the various blended aggregates in order to observe and identify which blend or blends, at which w/gps ratios give the best workability but with a zero slump.

It was determined previously that a w/gps of 0.16 would not be possible in the context of the mix design regime using 8 M NaOH concentration. In order to

prove this we will have to analyse the w/gps of 0.18 ate an 8M NaOH concentration. Under the parameters stipulated in GC1 at 8M and at a w/gps of 0.18 no water is added to the mix which means the only water present in the mix is the water in the NaOH solution and the sodium silicate solution. From this it can be deduced that for a w/gps of 0.16 to be achieved under the current parameters a certain amount of water would have to be taken out of the NaOH solution which would then mean that the concentration would not remain at 8M.

For this reason only the w/gps ratios of 0.18, 0.20, 0.22 and 0.24 were used for each blended mix i.e. blend 25, blend 28 and blend 44.

4.2.1.1 WATER TO GEOPOLYMER SOLIDS RATIO OF 0.18

Mixes made using all three blends viz. blend 25, blend 28 and blend 44 were found to be virtually impossible to mix. As the mixing progressed and dissolution started taking place the mix became so stiff that it interfered with the operation of the pan mixer. For fear of the pan mixer being damaged the mixing operation was ceased 3 minutes into the anticipated four minute mixing cycle.

The mix was removed and placed in the moulds; however the material showed distinct signs of having set. – flash setting.

All three blends experienced the same early setting. Upon discussion there have been reported instances of what is termed “flash setting” and has been evidenced in geopolymers made with slag or high calcium fly ash at other research centres in Australia (Koroluk 2008).

The visual impression from the minute the alkali liquid was added to the mix the material showed distinct signs needing more moisture. Geopolymer concrete using RCA has a characteristic dry look initially dry but as the liquid is mixed in the oily or glassy appearance starts to form and the mix settles down. At these

low w/gps there is no sign of the mix becoming plastic and workable again unless water is added but this would change and render the results invalid.

Another aspect that could be contributing to the poor workability could be the porosity of both the RCA and the bottom ash, or the fines portion of both aggregates or the fineness of the foundry sand. Even though the materials were brought to SSD condition the mix always looked as if it needed more water.

4.2.1.2 WATER TO GEOPOLYMER SOLIDS RATIO OF 0.20

All the mixes made with this water to geopolymer solid ratio were eventually possible, however flash setting did occur and the batch had to be discarded and remade on two occasions. What was noticeable was the colour and clarity of the chemicals especially if left for the period of 24 hrs as described. The sodium silicate was distinctly cloudy with a grey tinge.

What was also evident is that blends 25, 28 and 44 in that particular order have bottom ash percentages of 30%, 20% and 10%. Blend 25 was identified as being the mix with the lowest workability but the highest percentage of bottom ash.

The appearance of the mix was very stiff and dry but on the occasions where no flash setting was experienced, the mix consistency was very much what was envisaged. At the w/gps of 0.20 the appearance of the concrete was slightly on the dry side, and possibly what we would have expected.

No slump was evident.

4.2.1.3 WATER TO GEOPOLYMER SOLIDS RATIO OF 0.22

The w/gps ratio of 0.22 is the first mix design that showed any kind of workability. All three mixes were able to be mixed and placed in moulds with relative ease.

There was no evidence of flash setting even though the chemicals looked decidedly murky in appearance but once the water was added they seemed to settle, however it should be reported that when the plasticizer is added to the chemicals first, before the water, there is an noticeable increase in the viscosity but when the water is finally added it tends to stabilize.

When the mix was placed in the moulds and vibrated bleeding was evident on the surface of the geopolymer concrete. The slump recorded for the blends 25, 28 and 44 were 10mm, 21mm and 14mm respectively. The slump measurement must be delayed slightly as geopolymer concrete behaves differently to OPC concrete in that the “sticky” nature of the concrete requires the slump to be taken a while after removing the cone as the concrete is slow to slump.

4.2.1.4 WATER TO GEOPOLYMER SOLIDS RATIO OF 0.24

The ratio of 0.24 was according to GC1 a workable mix, however as this mix showed better workability it could be assumed that the foundry sand, bottom ash and the RCA fines reduced the workability relative to a mix consisting of natural aggregates.

There was no evidence of flash setting even though the chemicals looked decidedly murky in appearance as in the case of w/gps of 0.22. Plasticiser was used but possibly could be omitted, however this needs to be investigated.

When the mix was placed in the moulds and vibrated, bleeding was again evident on the surface of the geopolymer concrete in the moulds.

The slump recorded for the blends 25, 28 and 44 were 59 mm, 72mm and 63mm respectively. The slump measurement must be delayed slightly as geopolymer concrete behaves differently to OPC concrete in that the “sticky” nature of the concrete requires the slump to be taken a while after removing the cone as the concrete is slow to slump.

4.3 COMPRESSIVE STRENGTHS

Compressive strength testing was undertaken at Curtin University on an Avery 600 testing machine. Tests were conducted at 1 day (24hrs), 3 days, 7 days, 14 days and 28 days.

Figure 26: geopolymer concrete test cylinder

Table 12: Unconfined compressive strength test results for different blends at different w/gps ratios

W:GPS	BLEND	RATIO RCA:BA:FS	1 DAY	3 DAY	7 DAY	14 DAY	28 DAY
W/GPS = 0.16	25	60:30:10	NR	NR	NR	NR	NR
W/GPS = 0.16	28	70:10:20	NR	NR	NR	NR	NR
W/GPS = 0.16	44	70:20:10	NR	NR	NR	NR	NR
W/GPS = 0.18	25	60:30:10	NR	NR	NR	NR	NR
W/GPS = 0.18	28	70:10:20	NR	NR	NR	NR	NR
W/GPS = 0.18	44	70:20:10	NR	NR	NR	NR	NR
W/GPS = 0.20	25	60:30:10	3.6	3.2	3.3	3.7	3.8
W/GPS = 0.20	28	70:10:20	4.3	4.2	4.3	4.4	4.4
W/GPS = 0.20	44	70:20:10	3.6	3.7	3.8	3.9	3.9
W/GPS = 0.22	25	60:30:10	2.5	2.5	2.5	2.6	2.6
W/GPS = 0.22	28	70:10:20	2.8	2.6	2.7	2.9	2.9
W/GPS = 0.22	44	70:20:10	2.6	2.5	2.8	2.9	2.9
W/GPS = 0.24	25	60:30:10	1.3	1.1	1.3	1.4	1.4
W/GPS = 0.24	28	70:10:20	1.6	1.7	1.7	1.8	1.8
W/GPS = 0.24	44	70:20:10	1.5	1.5	1.6	1.6	1.6

Figure 27: Graph of unconfined compressive strength for different blends for w/gps = 0.20

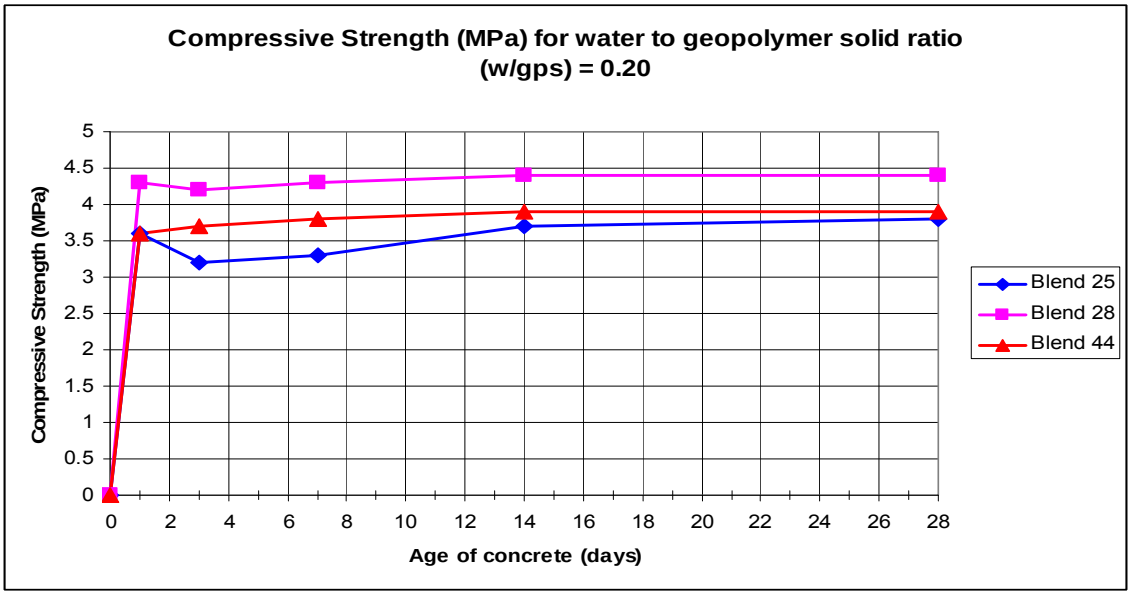


Figure 28: Graph of unconfined compressive strength different blends for w/gps = 0.22

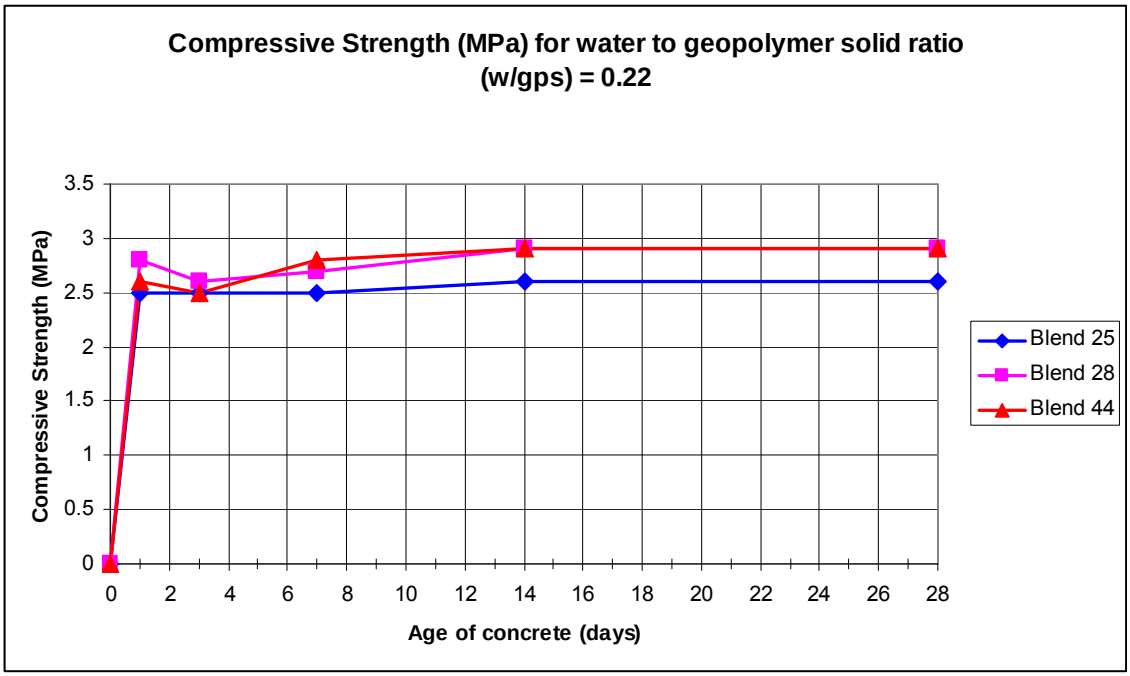
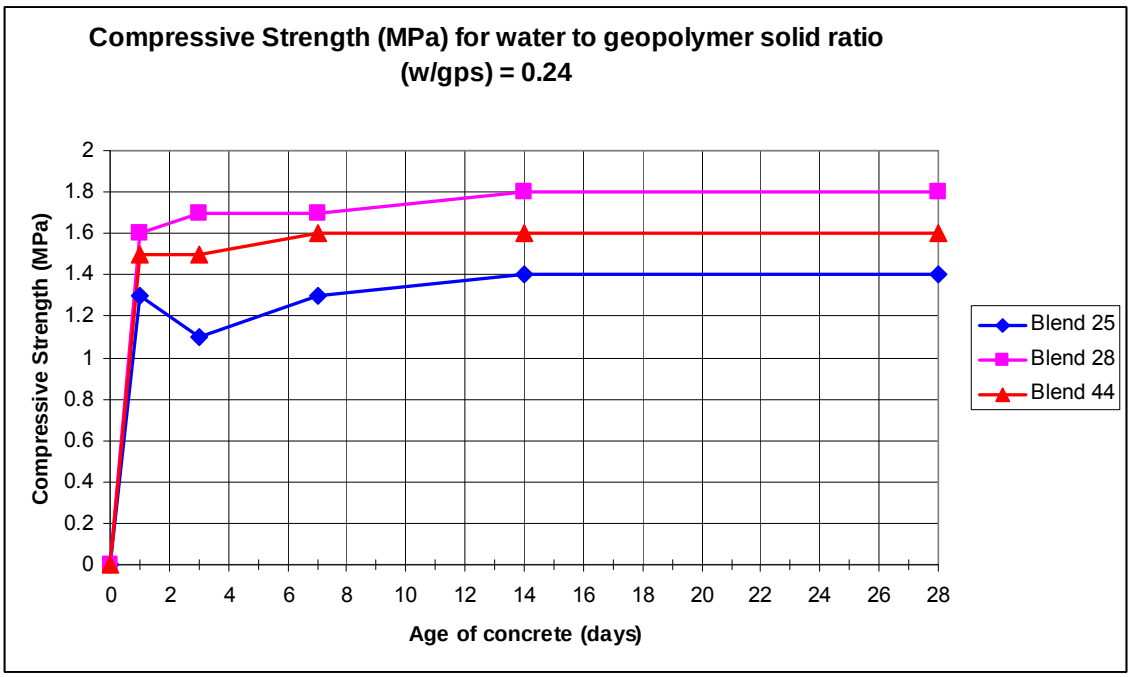


Figure 29: Graph of unconfined compressive strength different blends for w/gps = 0.24



The mixes at w/gps solids ratio of 0.18 experienced the phenomenon of flash setting and were unable to be effectively cast in moulds. Due to this there are no results for any mixes at w/gps of 0.18

The water to geopolymer concrete solids ratios of 0.20, 0.22 and 0.24 were able to be tested.

On demoulding after heat curing for 24 hours in the oven the samples presented a dry and black appearance. After testing the material felt brittle.

The data from the compressive strength testing shows they are substantially low in comparison with the design strength of 45 MPa, however it must be pointed out that the 45 MPa was for concrete made from natural aggregates. It was always accepted that there would be a reduction in strength due to the recycled aggregates but not to this extent. These strengths are also below the strength required by Australian standard AS/NZ 4455.1: 2008 and our target strength of 5 MPa. All three mixes at a w/gps ratio of 0.20 have compressive strength in the region of 3.6 MPa which would be acceptable for producing large solid units.

In terms of the compressive strength relationship to w/gps ratio the relationship prescribed in GC1 holds true i.e. the compressive strength of the concrete is reduced as the water is increased.

There is a noticeable and characteristic initial sharp strength gain as a result of the heat curing; however there is a slight dip noticeable at approximately three days and then a very gradual but slight increase up to fourteen days but no increase looks possible after 28 days. This is in line with the compressive strength gain with time prescribed in GC1.

What can be deduced from this data is an indirect relationship between the percentage bottom ash and the compressive strength. Blend 25 had 30% by weight and recorded the lowest strength readings of all w/gps ratios. Blend 44 has 20% bottom ash by weight and recorded the second highest compressive strengths at all three w/gps ratios. The mix with the least amount of bottom ash by weight was blend 28 and this recorded the highest strength gain of all three w/gps ratios measured.

5. SUMMARY AND CONCLUSIONS

5.1 GENERAL

This chapter summarises the various procedures, methods and results from this research. Each phase of the process has shown geopolymer concrete to be a new and ever evolving technology that has many benefits, especially in the current environment of climate change and global warming. Technology as such needs to be developed by looking for different ways to improve the technology, different approaches, questioning the existing technology in the hope of improving it, or discovering more.

Not all of these paths will lead to glory but nonetheless on a philosophical level any result in research has to be considered a good result.

The results from this research are not entirely what were expected, however, they have proved a vital part in the quest to understand the scope and limits of geopolymer concrete technology. From this research there are many avenues that have opened up and need exploring.

So much waste is being generated in the world so if any hope of improving, or merely sustaining, current levels is to be achieved then real and practical technologies need to be developed. This research attempted to do that. Power generation using coal will continue for many years as coal is a cheap and abundant source of energy. Alternative solutions are being developed but these are still many years off before real benefits are seen. Besides Australia, the developing world continues to build coal fired power stations and therefore this technology, once developed, can be used in a world wide context. The

abundance of fly ash and bottom ash that are currently being placed in landfill will be arrested if ways are developed to utilize these wastes effectively.

Building waste and where to put it is a problem for governments and municipalities and as economies develop and expand the problem is exacerbated. Being able to utilize this waste is the fundamental key to begin to solve some of these issues and problems. Projects such as Zero Waste to Landfill initiative show positive signs in that people and regulators are prepared to get involved but if practical solutions are not presented to them the cycle just continues.

The foundries, especially the medium to smaller ones do not have the turnover or cash flow to recycle their sand, however all sand eventually gets wasted in landfill. The sands are of sufficient quality to be reused in concrete and more research is needed to improve them by possibly blending them with other wastes such as glass or shot –blasting media or even with natural sands.

In line with the main aim of this research being that of establishing whether geopolymer concrete can be manufactured using 100% of the recycled aggregate materials and wastes from Kwinana industrial precinct the answer is yes.

From the results of this research the following conclusions can be drawn:

5.2 RECYCLED CONCRETE AGGREGATES (RCA)

Recycled concrete aggregate does not come from production lines as in the case of natural aggregates where there is a large range of products to choose from. Most recyclers in Western Australia produce only a basic all-in subbase which means that the fines and all the various building waste are crushed together through a jaw crusher and onto a stockpile.

This “all-in” product is not conducive to making any form of concrete as there is abundance of organic materials, gypsum products, plastic and wood to name a few present and if quality and consistency are important then these basic products will not suffice.

Recycled concrete aggregates quality depends largely on the source of the parent material. This feed stock, if contaminated, will affect the concrete in a negative way so it is important to examine the source of this material.

The decision to purchase an impact crusher and crush the recycled concrete at the lab enabled far more options with regard to size, shape and grading of the aggregates. The flexibility and versatility of being able to experiment with different gradings and to use these to blend with other aggregates has proven to be a valuable tool in designing mixes.

Another advantage of crushing on demand was that large quantities could be crushed specifically for each batch.

The combinations of the two crushes enabled the stone to be crushed in a manner that was consistent with real life practices enabling the size, shape and grading of the stone to be consistent with that produced in a commercial quarry.

Important observations and measurements were able to be taken regarding the amount and composition of the fines produced. From these observations it was established that these fine are porous and angular and have a noticeable effect on the workability of the mix. Even SSD moisture these fines influence the workability of mix in a negative way.

Crushers can be used in combination so that the fines are kept to a minimum and the RCA is utilized to its maximum. Aggregates that have no fines at a predetermined level can then be blended more accurately with other waste

streams or with natural aggregates to optimize the performance of these materials.

Recycled aggregates are porous relative to natural aggregates and therefore moisture at SSD is difficult to consistently determine due to the inconsistent make up of the material. SSD for one aggregate batch is often not the same for another. This varying SSD has a noticeable effect on the workability and strength on the geopolymer concrete

5.3 BOTTOM ASH AS AN AGGREGATE

This research has only considered one type of bottom ash from Kwinana Power Station.

A dilemma with bottom ash as it has very large pieces interspersed with predominately a very fine material. This decision to treat this as a fine or coarse material causes the dilemma. The coarse material is too large to use and need to be crushed which is costly. The fine portion of material would possibly be more effectively used as a source of Al and Si but then would have to be ground which would require energy and cost.

Bottom ash is porous in nature and this porosity varies which affects the free water in the mix if the aggregates are not at SSD at the time of mixing. A visual observation is that the greater the percentage of bottom ash in the mix the dryer the mix looks visually and the workability is noticeably reduced. This is due to the large fines fraction present in the bottom ash.

Kwinana Power Station’s efficiency as a power station is considered poor in comparative terms resulting in the bottom ash from Kwinana having an LOI of around 21% which is substantially above the recommended limit of 5% prescribed for making geopolymer concrete. (Fernández-Jiménez and Palomo

2003) This unburnt coal is very angular in shape as can be seen in Fig.18. The photograph was taken in a fly ash sample from Kwinana Power Station but the theory can also be applied to bottom ash. The angularity of the coal reduces the workability of the mix.

What is evident from the compressive strength results is that there is a reduction in compressive strength with a corresponding increase in the percentage of bottom ash. The idea originally assumed that the bottom ash would play a duplicate role as an aggregate and as a provider of Al and Si ions and thereby increase the polymeric reactions - this seemingly did not occur. This is an area that requires further investigation.

Bottom ash is also thought to be responsible for flash setting. It is believed, however there is no evidence, that calcium in the bottom ash could accelerate setting. The calcium reaction is normally caused from high calcium (> 20% CaO) ashes, however the bottom ash used in this research is low at 2.3% so the possibility of the calcium content being implicated in the flash setting is low.

5.4 FOUNDRY SAND

The foundry sand used in this research was of a superfine grading, majority of the particles in the 300 μm range. These fine natural sand particles have the potential to exert a negative influence on the workability of the mix.

An observation in the mixing process was that the foundry sand attracted the majority of the fly ash to it and the RCA aggregate was noticeably clean. This can only be due to the resins or chemicals in the foundry sand as this does not appear to be the case in dry mixing with natural aggregates. The effect of the resins and catalyst in the foundry sand is unknown and is an area that needs further investigation.

Foundries do use coarser sands in other processes as they are more cost effective since quality is the determining factor. These other coarser foundry sands need to be investigated and their possibilities assessed.

5.5 BLENDED MATERIALS

Based on the aims of this research the intention was to use 100% of recycled material available in Kwinana industrial precinct. The purpose of attempting to make concrete from a number of waste materials is that the benefit is felt across a number of industries.

The blending is an essential part of this research and considerable time has been spent attempting to utilize the recycled concrete aggregate, bottom ash and foundry sand as effectively as possible and within the parameters of proven concrete practices.

The three blends out of seventy five blends chosen met the prerequisite in that they all fell within the maximum packing envelope and utilized all the waste materials. Looking ahead, the possibilities are abundant; the more materials in the blend the better the crossover of properties and industries. This research attempted to initiate a process of utilising wastes generated in a localized area but the possibilities exist to expand to all wastes in all areas.

The process of blending is a time consuming process, however the benefits are vast. Blending allows flexibility, enhances properties by crossover and reduces the very time consuming trial and error process. The software used was slow and requires more development and improvement in order to become more user friendly, however it is accurate across most sieve sizes, more so than the tried and tested graphical or calculation methods. Visual impression of the blended mixes was that they appeared continuously graded.

5.6 FLASH SETTING: ALKALI ACTIVATING LIQUIDS, WATER AND PLASTICISER

Flash setting can be described as the unpredictable phenomenon of early onset rapid hardening of the mix. This can occur during mixing of chemicals, during mixing in the mixer or after mixing. What this means is that at any stage without warning the mix can unexpectedly harden. If it is during a critical stage in the mixing or whilst placing and compacting into moulds the whole mix is lost and has to be redone.

All the effort and preparation is lost and in most case all the materials. During the time of this research there have been reports of flash setting amongst a number of researchers; postgraduates and undergraduate.

Curtin University is not alone in experiencing flash setting as has been discovered in an online article featuring research at Melbourne University. (Koroluk 2008).

There are a number of causes of flash setting; however it can be one or a combination of possibilities. The causes identified by the Department of Civil Engineering at Curtin University are as follows:

5.6.1 Ambient temperature

Most cases of flash setting occurred during the colder months of the year. NaOH is known to freeze at temperatures below 15 degrees Celsius. Sodium silicate is known to be unstable and in most industrial applications temperature control is maintained on sodium silicate storage facilities. The ambient temperature affects the temperature of equipment and tools which is also believed to play a role.

5.6.2 Sodium Silicate

Besides the instability of sodium silicate at low temperatures, the age of the silicate could have a major effect on the flash setting. What has been observed is that sodium silicate is usually clear but as the container ages; the material in the drum oxidizes and becomes cloudy. The silicate that was used was cloudy and flash setting was experienced, however, when this was replaced with a new drum the flash setting occurred as well. On inspection of the drum of sodium silicate it was thicker at the bottom than at the top. A pump was purchased and the silicate was circulated within the drum. The frequency of the flash setting reduced but the ambient temperatures were also increasing as summer was approaching so it is not known which factor was responsible for the reduced occurrence of flash setting.

5.6.3 Portland cement contamination

This is one of the most widely promoted reasons for flash setting. It is believed that utensils, equipment or the cement dust from making OPC concrete in the same laboratory can cause flash setting. Great lengths were taken to ensure that all the equipment and utensils were cleaned with soap and water to ensure that the risk of contamination was reduced as far as possible. However this was inconclusive as the flash setting re-occurred.

5.6.4 Fly ash contamination from high calcium bottom ash

This is a proposal by Prof. Rangan. Fly ash at the utility can become contaminated with bottom ash. The bottom ash used in this research has very low CaO at 2.3%.

5.6.5 Low water geopolymer mixes

Mixes with low water to geopolymer solids experienced more flash setting than mixes with higher water contents. This was found to be the case in this research when the mix with water to geopolymer solids (w/gps) of 0.18 was made. If water is added to the mix at the onset of flash setting the mix reverts to a normal workability but strength is compromised and become compromised.

5.6.6 Molar concentration of NaOH

It has been observed that mixes with higher molarities of NaOH experience flash setting more frequently. This research used only 8 Molar NaOH.

5.6.7 24 hr pre-mixing of sodium silicate and sodium hydroxide

The alkali premixed solution is highly reactive after 24hrs especially at higher molarities of NaOH. GC1 prescribes that the chemicals be mixed 24 hrs before mixing; however there is a definite swing away from this as many researchers have adopted a 2hr premixing period before mixing. From observations in this research we deduce that the 24hr period needs further investigation.

5.6.8 Addition of superplasticiser to the alkali activator solution

It was observed that when the superplasticiser is added before the water, the alkaline liquid mixture becomes more viscous on some occasions. This possibly explains that at low water to geopolymer solid ratios, for instance 0.18, where no additional water is added to the alkaline liquid and only the plasticizer is added, the flash setting occurred. In instances when the water is added first, viscosity remains constant.

5.7 GEOPOLYMER CONCRETE

5.7.1 FACTORS AFFECTING THE PERFORMANCE OF THE MIX

The geopolymer concrete made in this research proved that recycled concrete using 100% waste materials is possible, however compared with normal aggregates the material is substantially lower in strength.

5.7.1.1 COMPRESSIVE STRENGTH

The factors that could be responsible for this reduced strength are as follows:

- The high carbon content of the fly ash.
- The high carbon content of the bottom ash.
- The variable moisture absorption of the recycled concrete aggregate due to the variability in feed stock and its effect on SSD of the batch.
- The differential moisture at SSD of the fine aggregate fraction due to variations in feedstock.
- The moisture absorption of the bottom ash due to its porosity and the variability of this porosity on the SSD of the batch sample.
- The low molar concentration of Sodium Hydroxide at 8M.

5.7.1.2 WORKABILITY

The factors influencing the workability of the concrete were as follows:

- The water to geopolymer solids ratio. The mix is very sensitive to water and the difference in water between 0.18 and 0.20 has a substantial

effect on the workability, in line with GC1. More research is required in this area, however for mixes using recycled materials the ratios for w/gps as set out in GC will possibly have to be revised.

- The fineness and singularity of particle size of the foundry sand.
- The shape, angularity and flakiness of the fine aggregate fraction of RCA and its differential water demand.
- The shape and angularity of the LOI in the bottom ash as well as its porosity and varying water demand.
- The plasticizer at 1.5% of mass of fly ash possibly increased to the limit of 4%.
- Flash setting

5.7.1.3 HEAT CURING

Heat curing for a period of 24hours had and immediate and rapid effect on the strength gain but what was noticeable was that in a number of mixes there was a slight drop in the compressive strength at day three which recovered at day 7 and from then on there was no noticeable gain.

The results of the heat treatment were in line with those set out in GC1(Hardjito and Rangan 2005)

5.7.1.4 DRY MIX

One of the aims of this research was to investigate at what water to geopolymer solids ratio (w/gps) would constitute a “dry mix” for the making of geopolymer concrete products. From this research a w/gps ratio of 0.20 would be adequate but further testing at w/gps of .21 would be recommended.

6. RECOMMENDATIONS

As this research is considered the first phase in a multi-phase research program, investigating possible avenues for utilizing waste by recycling them into resources and products that can compete in the market place without any inferiority, is the final goal. In order to achieve this end goal it was possibly best to start with an ambitious agenda such as 100%of materials to be waste products. As a result of this research new paths have opened up and new ideas spawned and using these as a basis the following is recommendations are made:

- To develop a method for crushing recycled concrete aggregates (RCA) in order to end up with an optimum grading with as little production of material below the 4.75mm sieve (fines fraction).

- To establish at what sieve size the fine fraction of RCA starts influencing the workability.

- Blend RCA with coarse natural sand and foundry sand as aggregates for geopolymer concrete.

- Blend RCA with crushed glass in place of coarse natural sand.

- To establish to what extent the LOI has an effect on the compressive strength of geopolymer concrete. Bottom Ash and fly ash from alternative sources with LOI's within the recommended limits be used as controls. To remove the LOI from the fly ash and investigate the difference in strength gain.

- To grind or mill the bottom ash and to use as a source of alumino-silicate material in the manufacturing of geopolymer concrete.

- To Grind or mill the fly ash to establish to what extent the grinding has on the reactivity of the fly ash.

- To determine the effect moisture has on the reactivity of the fly ash and whether it can be used in a moist condition as found in landfill or whether it requires drying.

- Foundry sands from other foundries to be sourced, analysed and used in making geopolymer concrete blends.

- Investigate the phenomenon of flash setting with regards to:
  - Ambient temperature
  - Sodium silicate temperature instability
  - Sodium silicate age, oxidation and circulation.
  - Portland cement contamination
  - Calcium contamination.
  - Investigation into an optimum premix period for alkali chemicals for specific molar concentrations.
  - Low water geopolymer mixes.
  - High NaOH molar mixes
  - Superplasticiser effect.
  - Potassium based system

- Investigate electronic measurement of the moisture contents of aggregates and fly ash just prior to mixing, and throughout the mixing phase to accurately measure the moisture at any time and develop an optimum, or SSD blend moisture content immediately prior to adding the alkaline activator solution.

(Hardjito and Rangan 2005) GC1 developed the technology for low calcium fly as based geopolymer concrete which is a broad based technology with far reaching potential. For this technology to develop further all aspects need to be examined and improved, where possible, to make the technology more versatile and robust. The recommendations from this research are aimed at developing this technology so that it can be applied to real life environmental issues, to make a difference to the waste problems we face and assist in the global drive to arrest the causes warming our planet and changing or climate.

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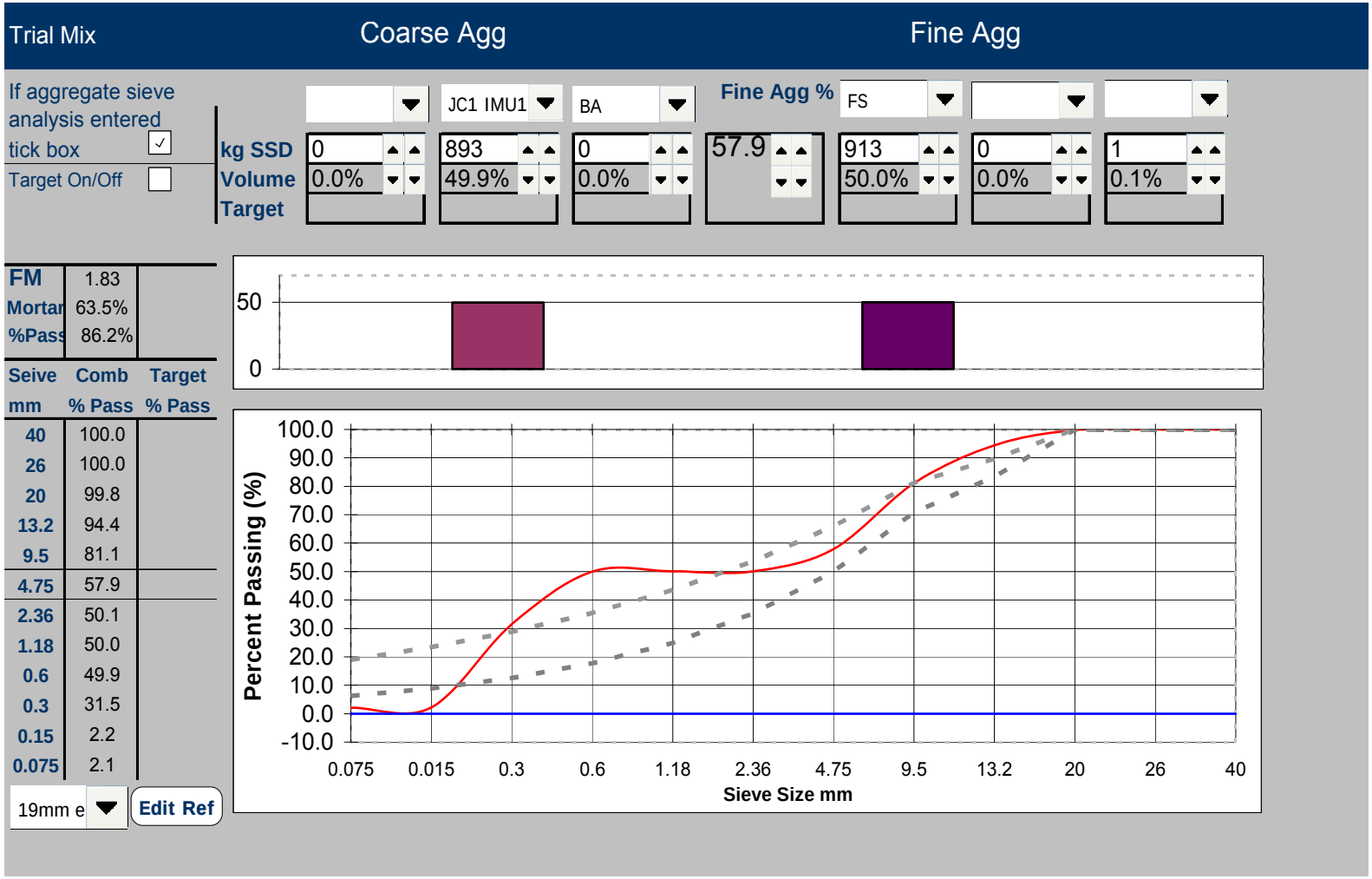
8. APPENDIX A: BLENDS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Fine Agg
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JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
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57.9
913
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0.0%
49.9%
0.0%
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FM 1.83
Mortar 63.5%
%Pass 86.2%
Seive mm
Comb % Pass
Target % Pass
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26 100.0
20 99.8
13.2 94.4
9.5 81.1
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1.18 50.0
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26
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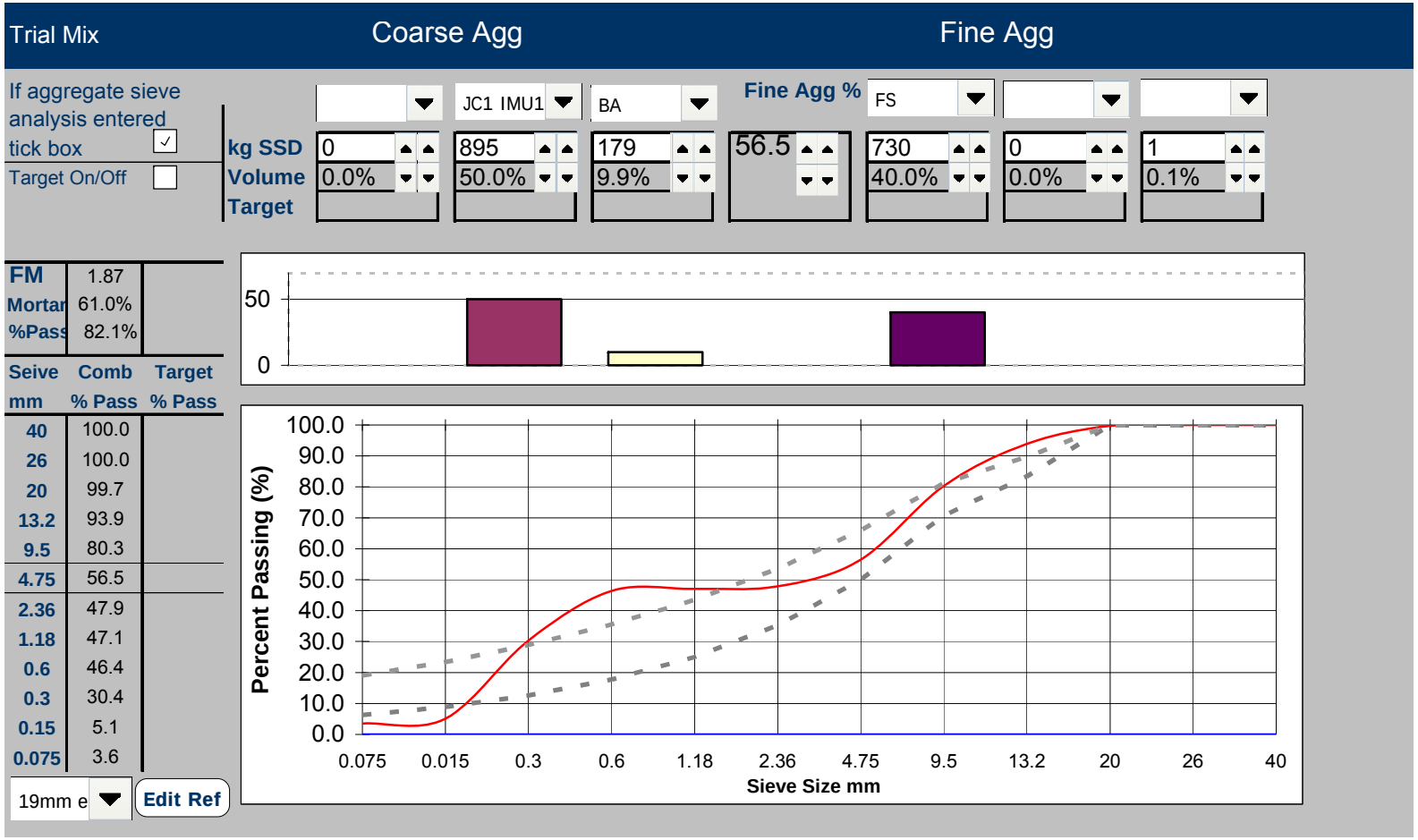
Sieve Size mm

Blend 1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Fine Agg
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Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
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179
56.5
730
0
1
0.0%
50.0%
9.9%
40.0%
0.0%
0.1%
FM 1.87
Mortar 61.0%
%Pass 82.1%
Seive mm
Comb % Pass
Target % Pass
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26 100.0
20 99.7
13.2 93.9
9.5 80.3
4.75 56.5
2.36 47.9
1.18 47.1
0.6 46.4
0.3 30.4
0.15 5.1
0.075 3.6
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10.0
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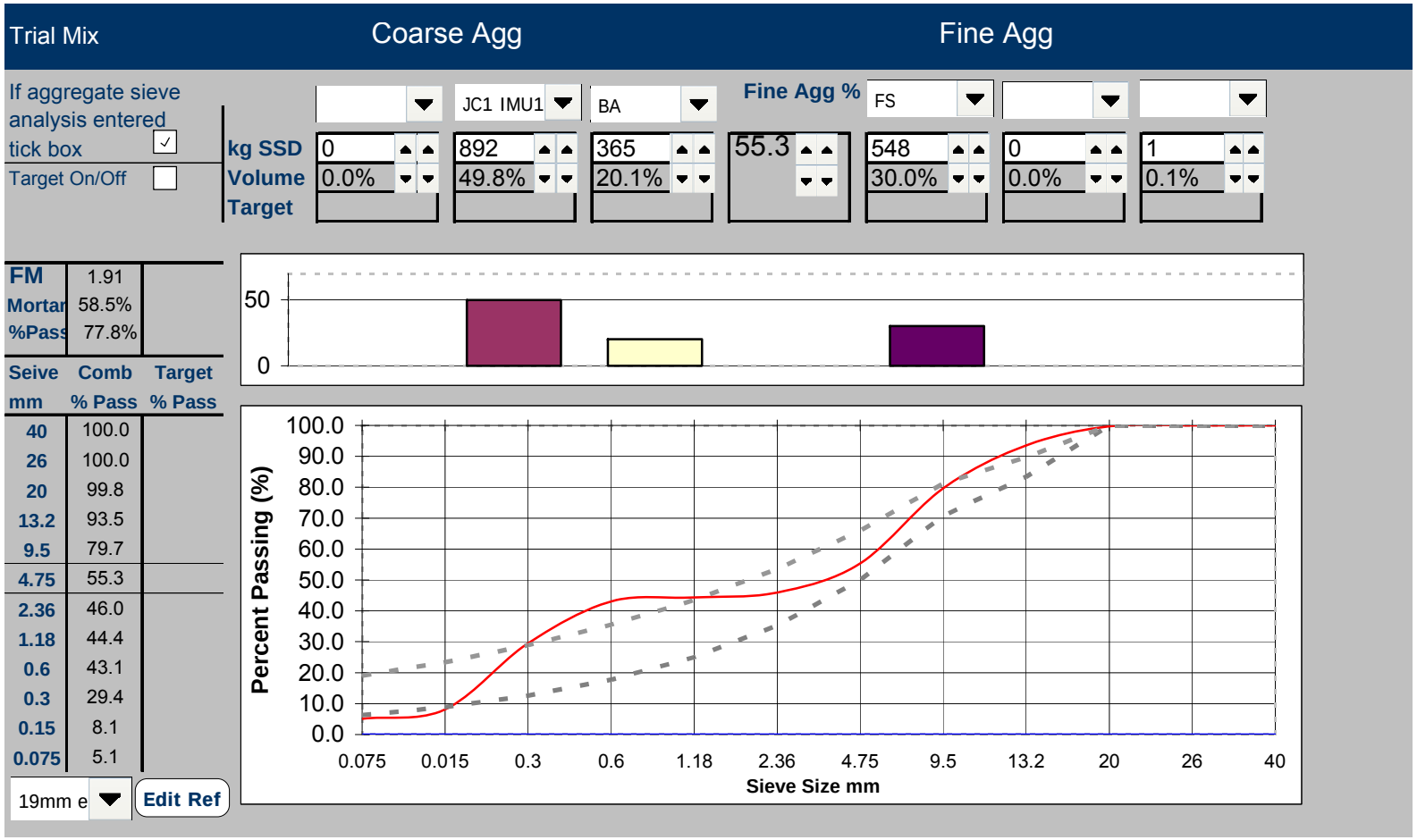
20
26
40
Sieve Size mm

Blend 2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Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
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365
55.3
548
0
1
0.0%
49.8%
20.1%
30.0%
0.0%
0.1%
FM 1.91
Mortar 58.5%
%Pass 77.8%
Seive mm
Comb % Pass
Target % Pass
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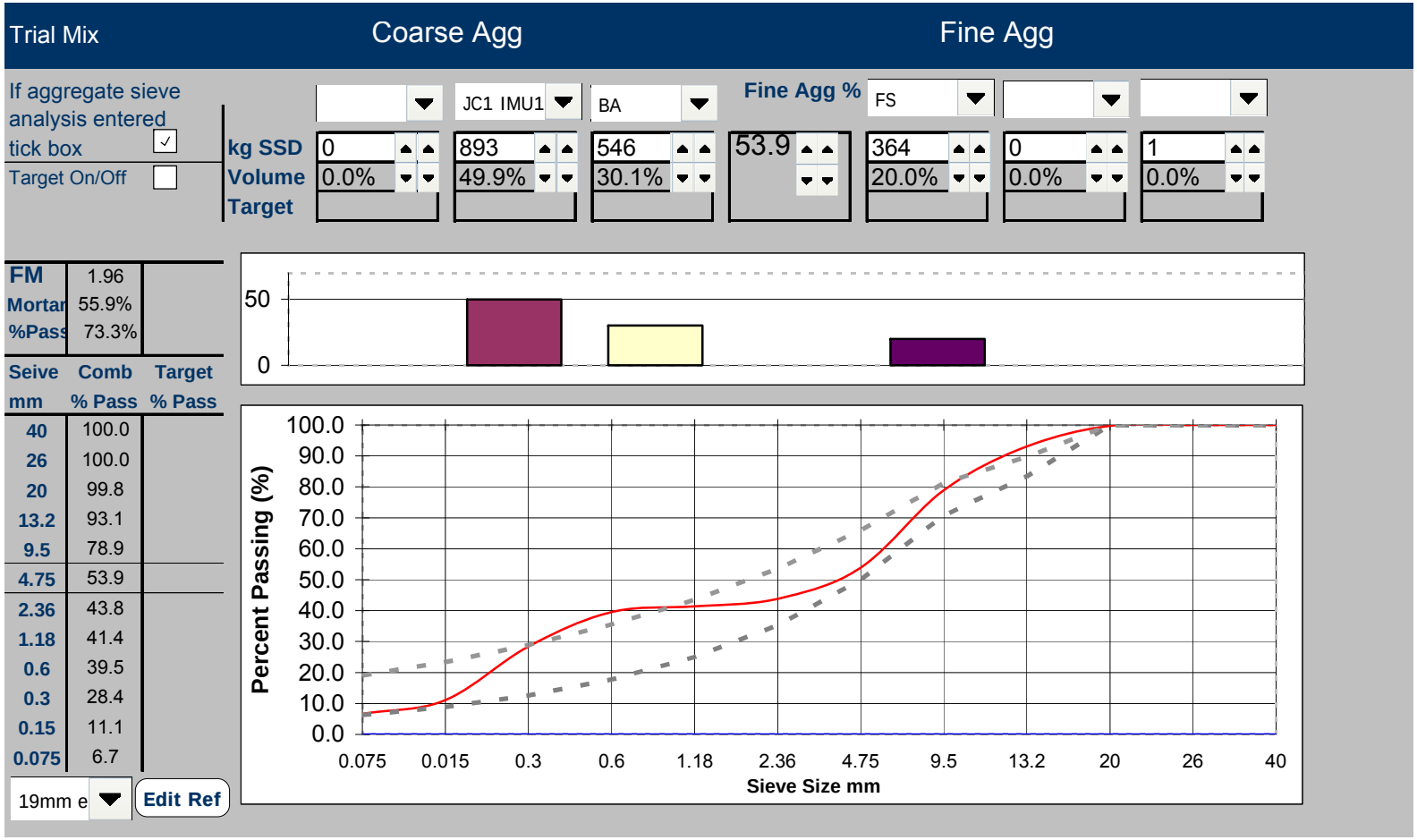
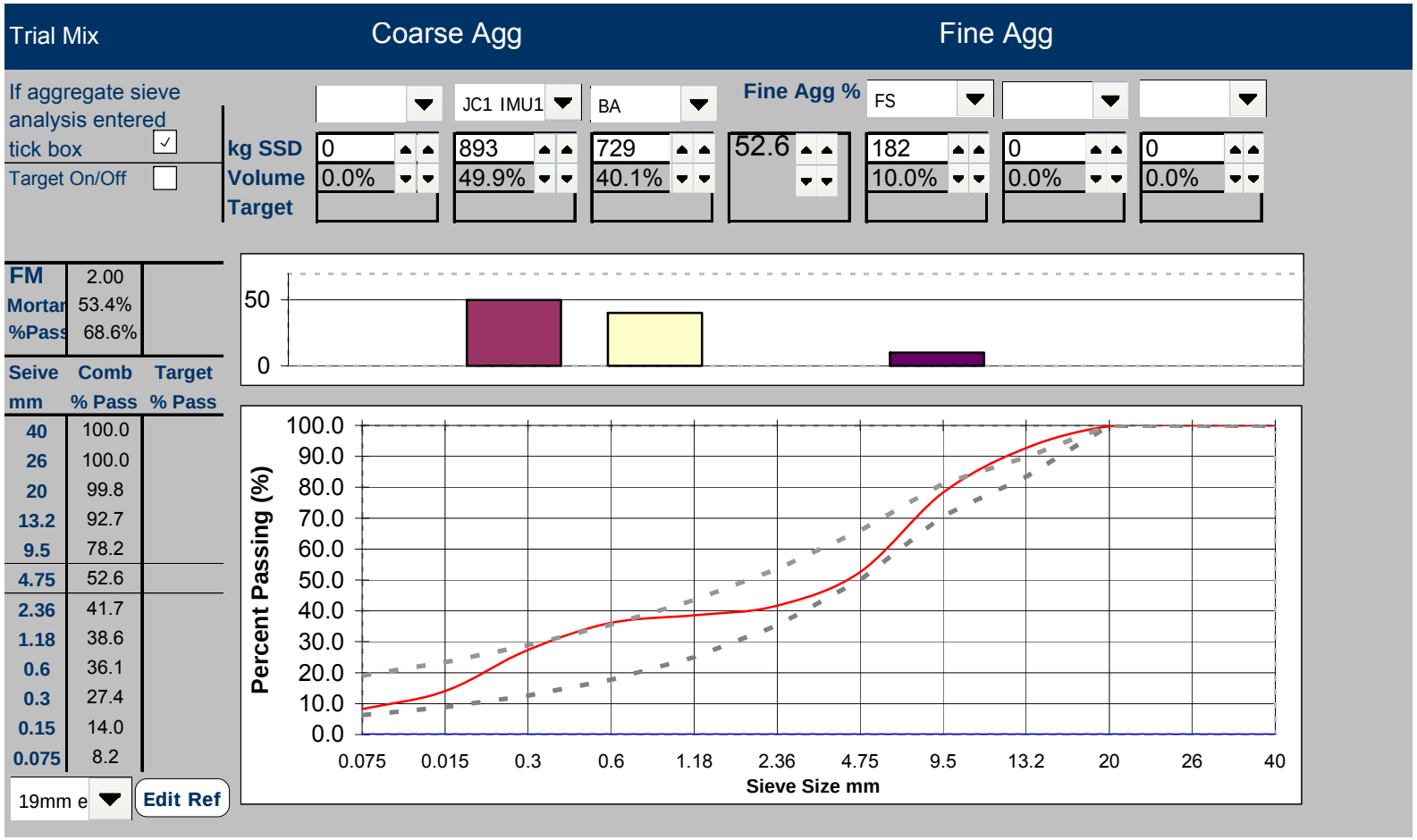
26 100.0
20 99.8
13.2 93.5
9.5 79.7
4.75 55.3
2.36 46.0
1.18 44.4
0.6 43.1
0.3 29.4
0.15 8.1
0.075 5.1
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

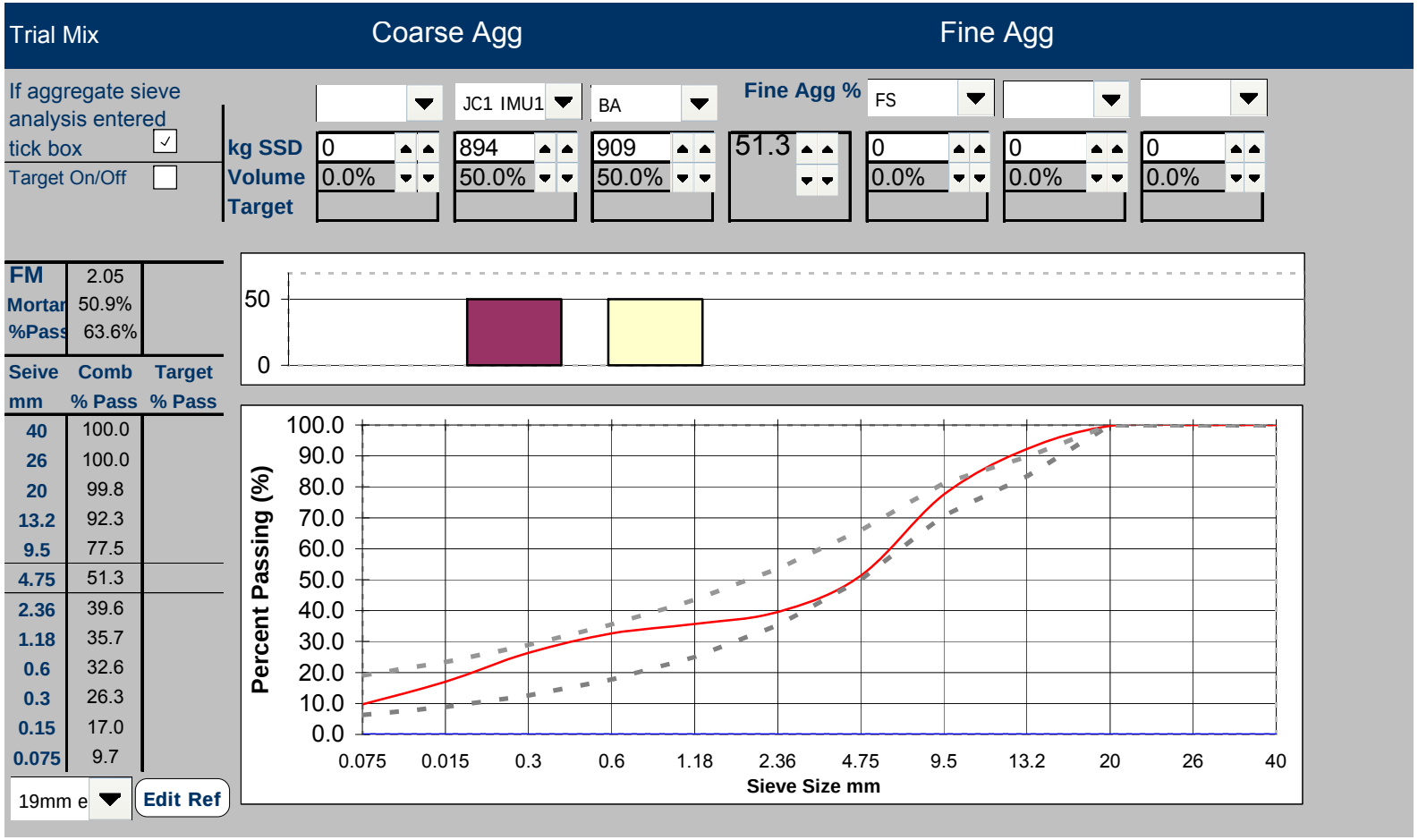
Blend 3


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
893
546
53.9
364
0
1
0.0%
49.9%
30.1%
20.0%
0.0%
0.0%
FM 1.96
Mortar 55.9%
%Pass 73.3%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.8
13.2 93.1
9.5 78.9
4.75 53.9
2.36 43.8
1.18 41.4
0.6 39.5
0.3 28.4
0.15 11.1
0.075 6.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

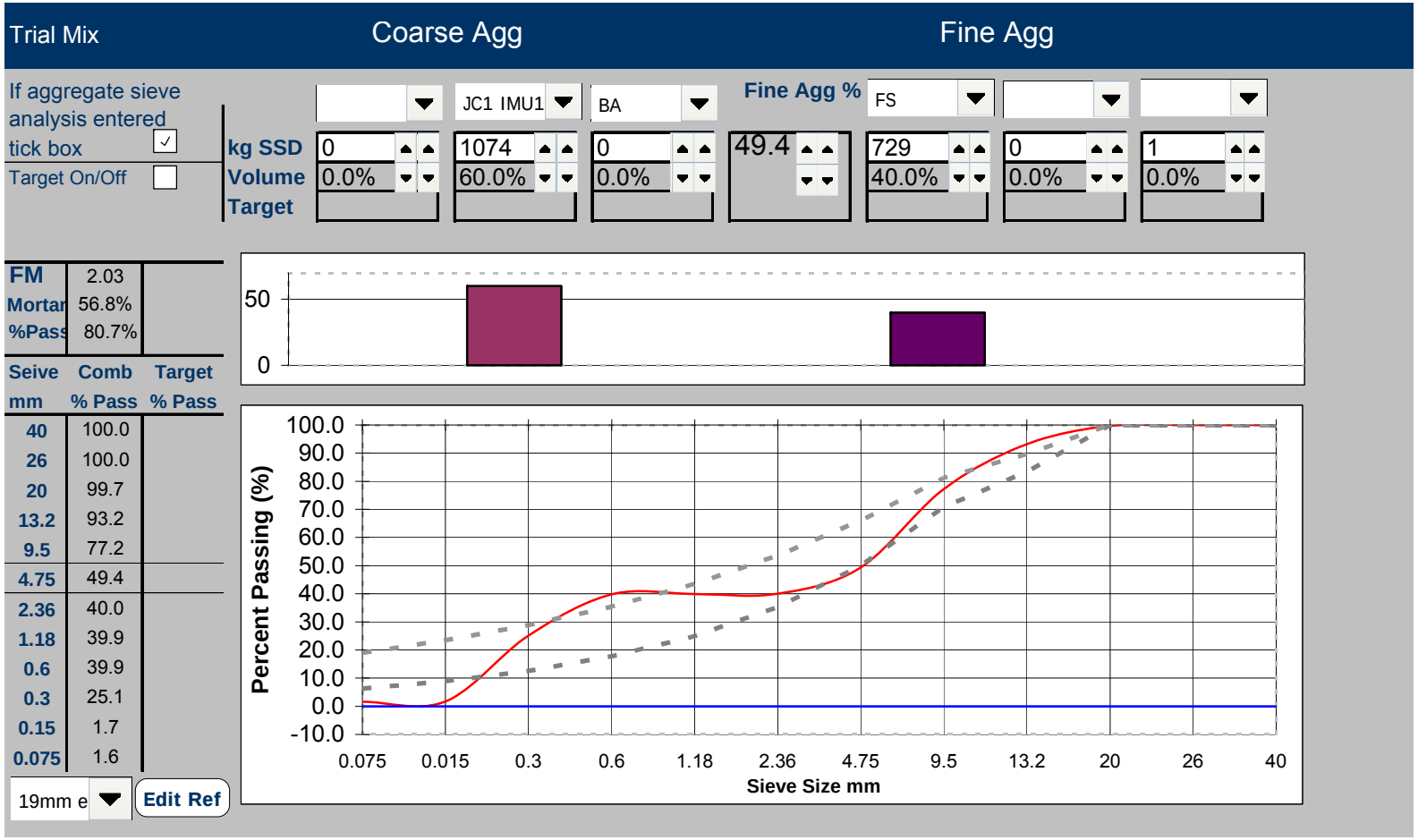
Blend 4


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
893
729
52.6
182
0
0
0.0%
49.9%
40.1%
10.0%
0.0%
0.0%
FM 2.00
Mortar 53.4%
%Pass 68.6%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.8
13.2 92.7
9.5 78.2
4.75 52.6
2.36 41.7
1.18 38.6
0.6 36.1
0.3 27.4
0.15 14.0
0.075 8.2
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

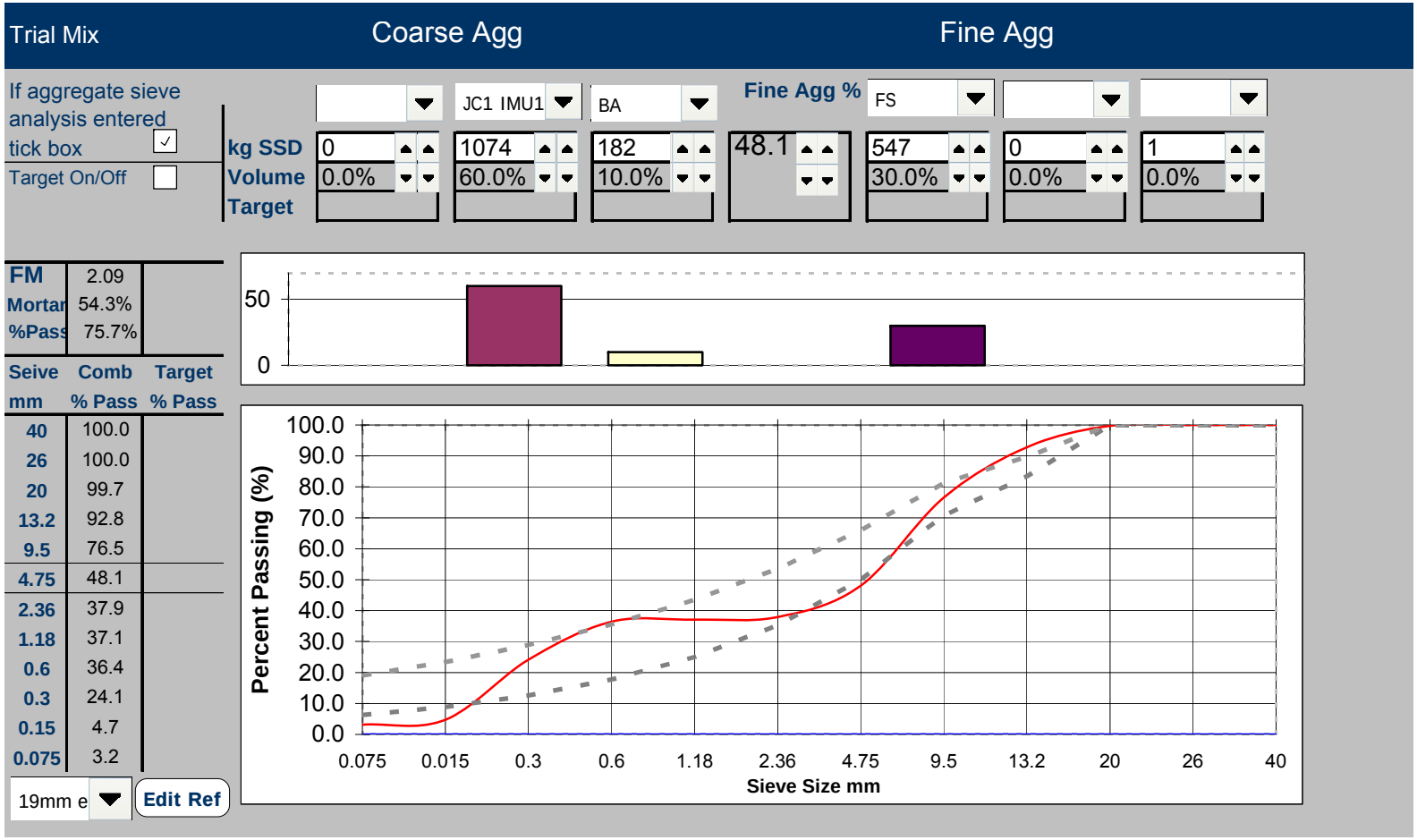
Blend 5


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
894
909
51.3
0
0
0
0.0%
50.0%
50.0%
0.0%
0.0%
0.0%
FM 2.05
Mortar 50.9%
%Pass 63.6%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.8
13.2 92.3
9.5 77.5
4.75 51.3
2.36 39.6
1.18 35.7
0.6 32.6
0.3 26.3
0.15 17.0
0.075 9.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

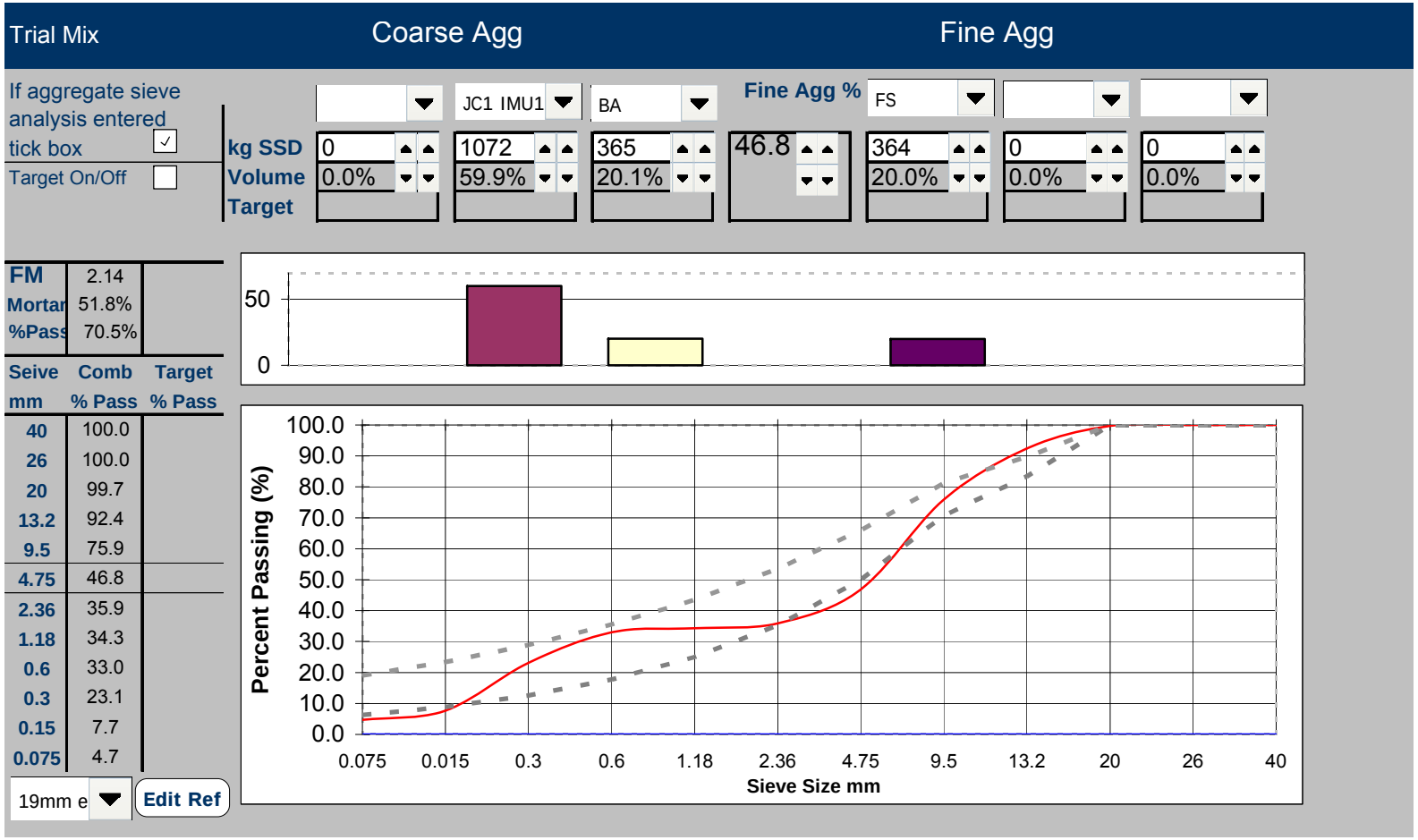
Blend 6


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1074
0
49.4
729
0
1
0.0%
60.0%
0.0%
40.0%
0.0%
0.0%
FM 2.03
Mortar 56.8%
%Pass 80.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.7
13.2 93.2
9.5 77.2
4.75 49.4
2.36 40.0
1.18 39.9
0.6 39.9
0.3 25.1
0.15 1.7
0.075 1.6
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

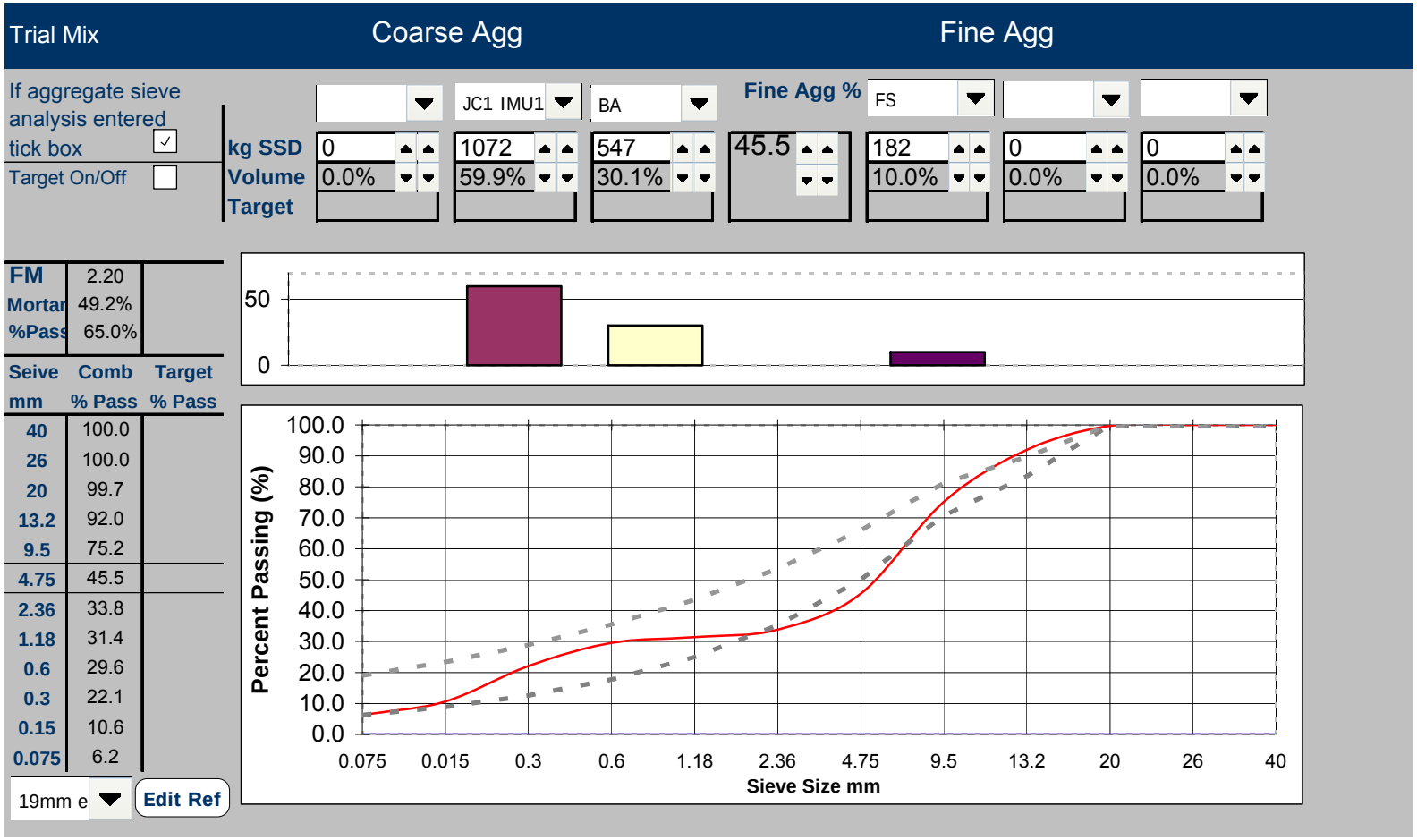
Blend 7


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1074
182
48.1
547
0
1
0.0%
60.0%
10.0%
30.0%
0.0%
0.0%
FM 2.09
Mortar 54.3%
%Pass 75.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.7
13.2 92.8
9.5 76.5
4.75 48.1
2.36 37.9
1.18 37.1
0.6 36.4
0.3 24.1
0.15 4.7
0.075 3.2
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

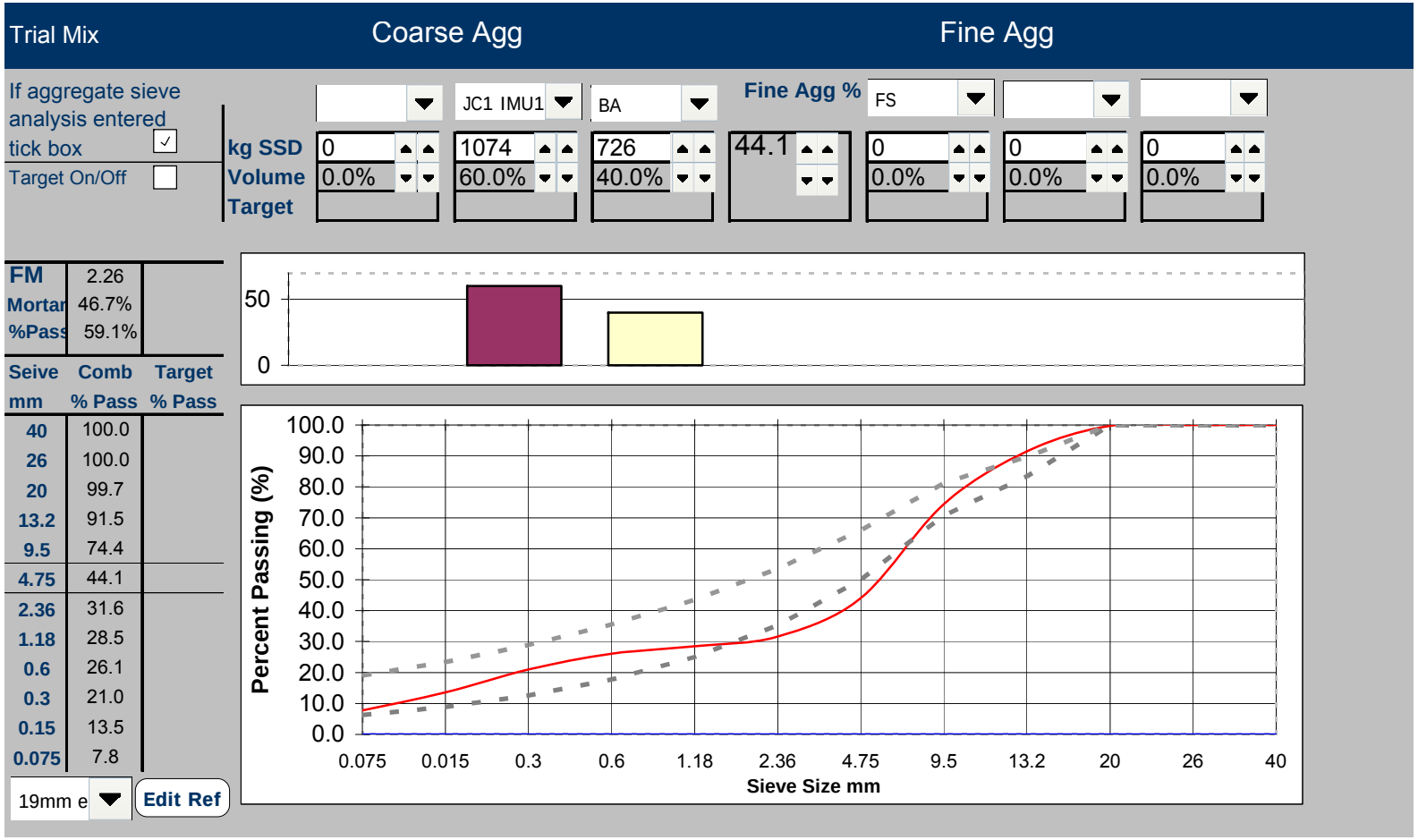
Blend 8


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1072
365
46.8
364
0
0
0.0%
59.9%
20.1%
20.0%
0.0%
0.0%
FM 2.14
Mortar 51.8%
%Pass 70.5%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.7
13.2 92.4
9.5 75.9
4.75 46.8
2.36 35.9
1.18 34.3
0.6 33.0
0.3 23.1
0.15 7.7
0.075 4.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

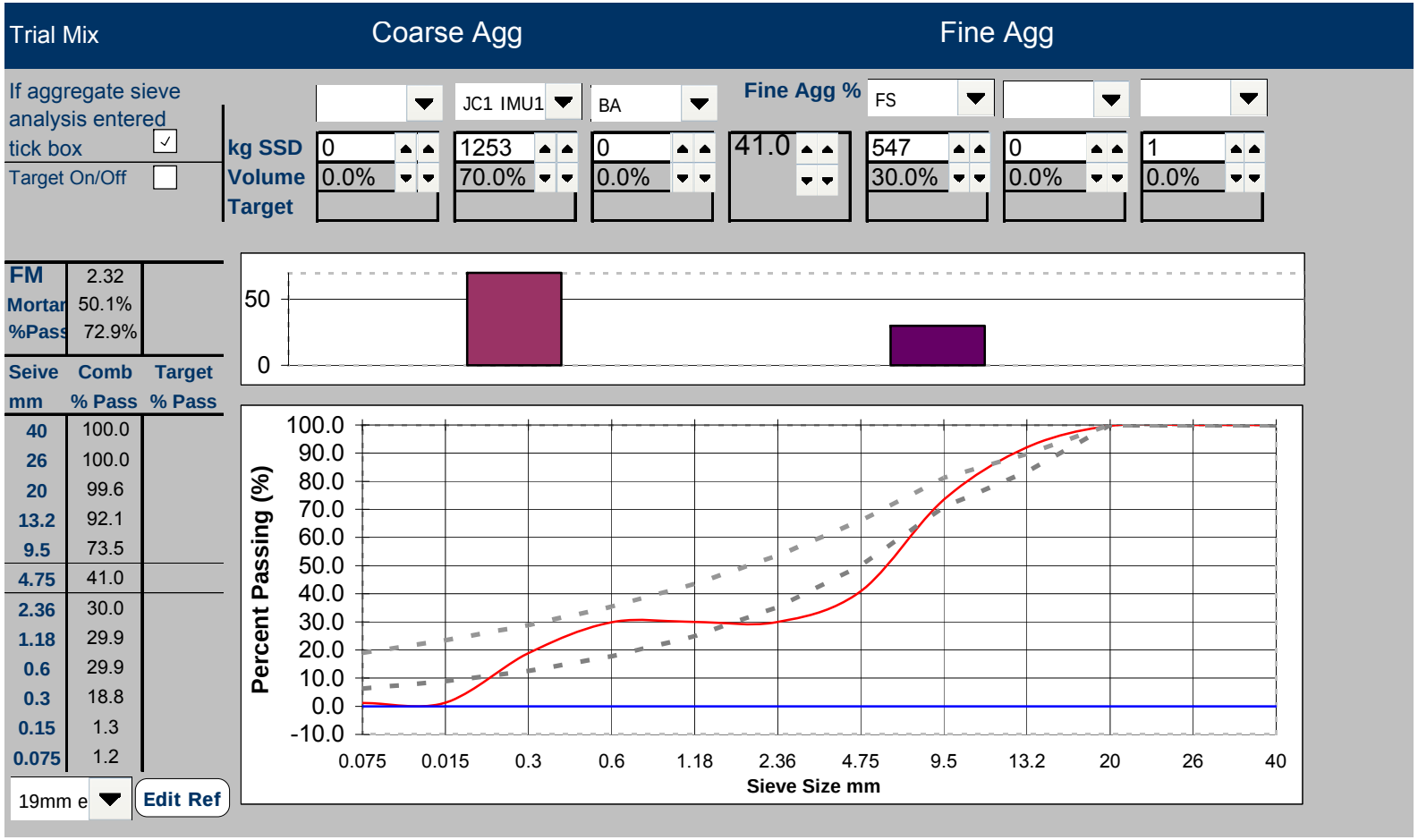
Blend 9


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1072
547
45.5
182
0
0
0.0%
59.9%
30.1%
10.0%
0.0%
0.0%
FM 2.20
Mortar 49.2%
%Pass 65.0%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.7
13.2 92.0
9.5 75.2
4.75 45.5
2.36 33.8
1.18 31.4
0.6 29.6
0.3 22.1
0.15 10.6
0.075 6.2
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

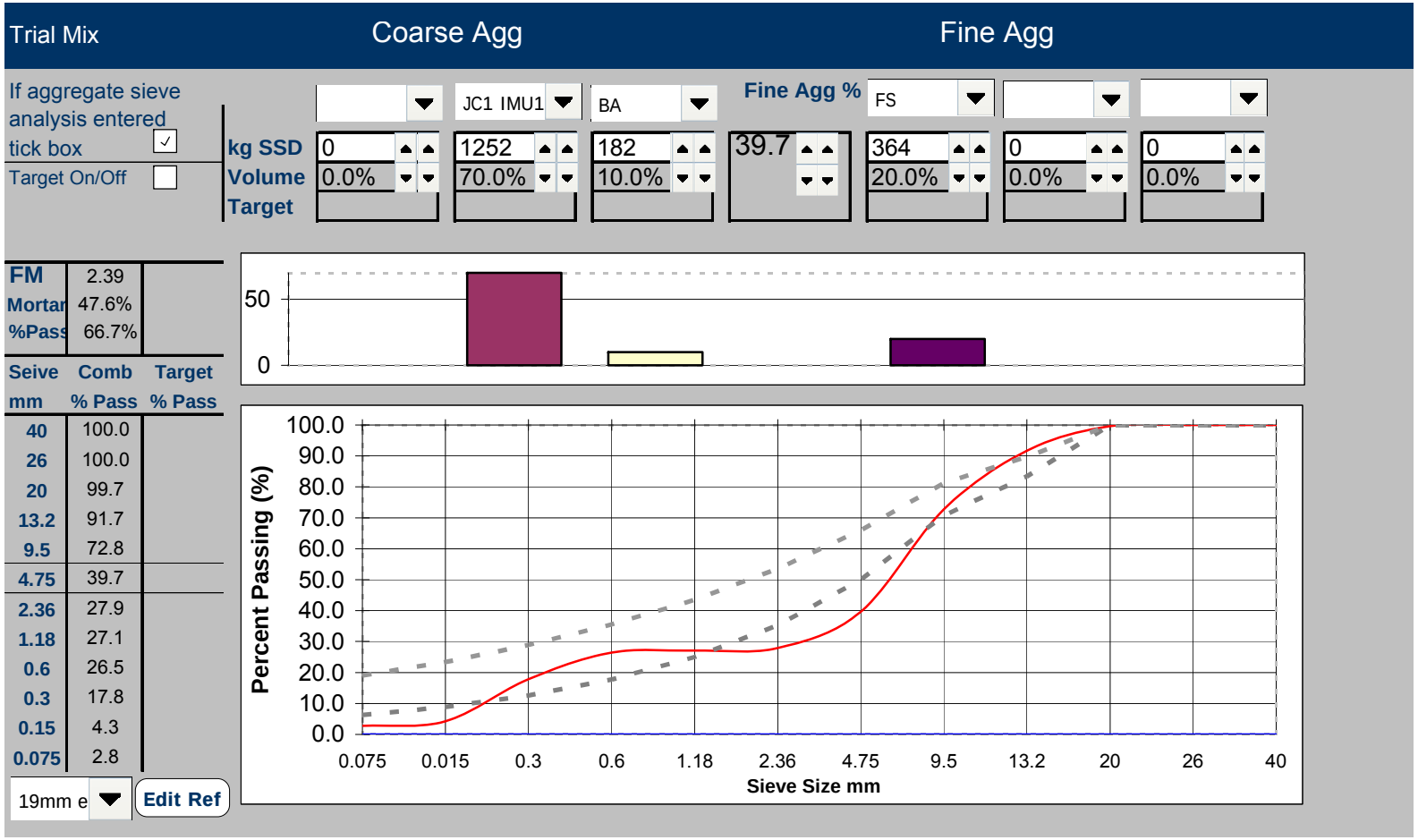
Blend 10


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1074
726
44.1
0
0
0
0.0%
60.0%
40.0%
0.0%
0.0%
0.0%
FM 2.26
Mortar 46.7%
%Pass 59.1%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.7
13.2 91.5
9.5 74.4
4.75 44.1
2.36 31.6
1.18 28.5
0.6 26.1
0.3 21.0
0.15 13.5
0.075 7.8
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

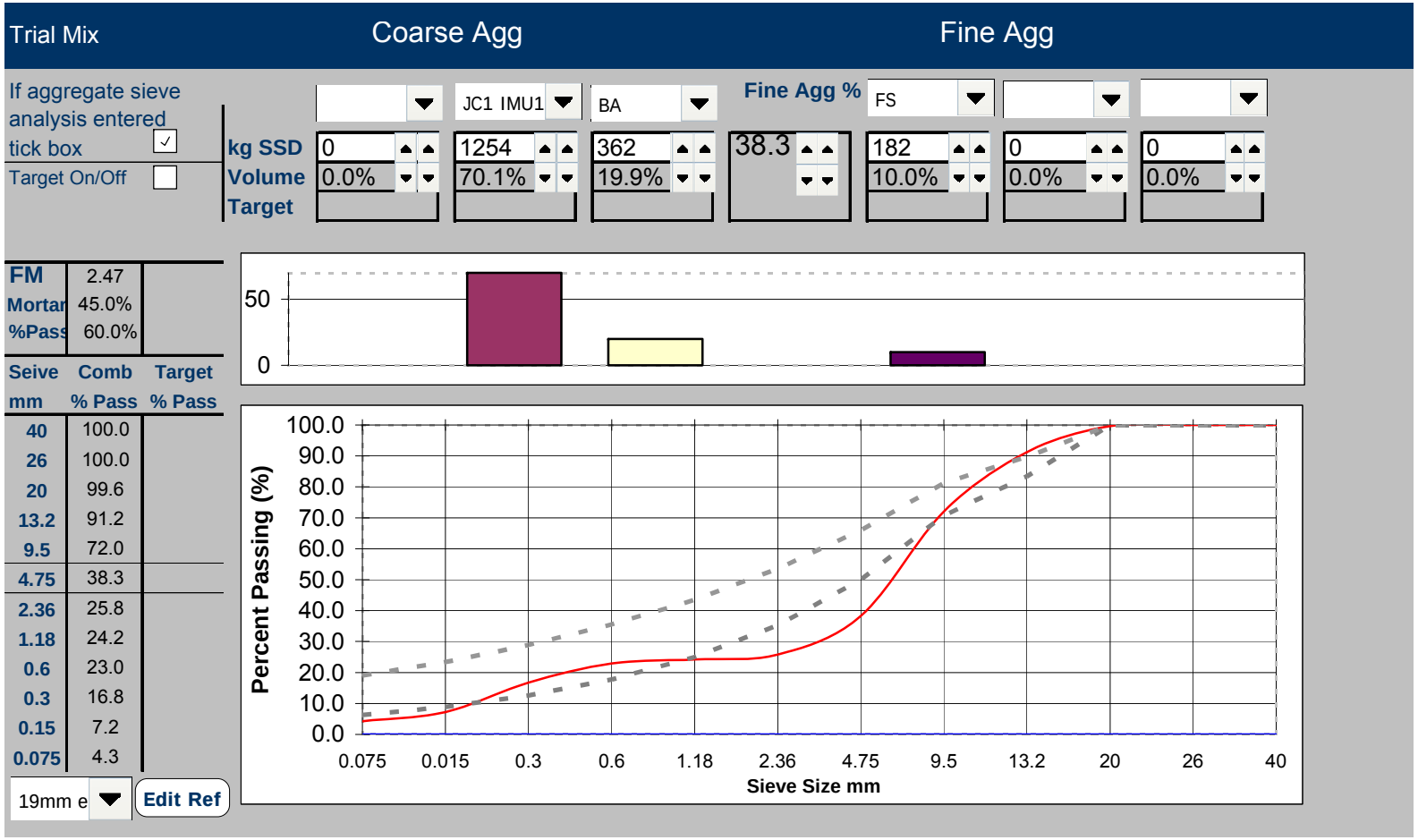
Blend 11


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1253
0
41.0
547
0
1
0.0%
70.0%
0.0%
30.0%
0.0%
0.0%
FM 2.32
Mortar 50.1%
%Pass 72.9%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.6
13.2 92.1
9.5 73.5
4.75 41.0
2.36 30.0
1.18 29.9
0.6 29.9
0.3 18.8
0.15 1.3
0.075 1.2
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

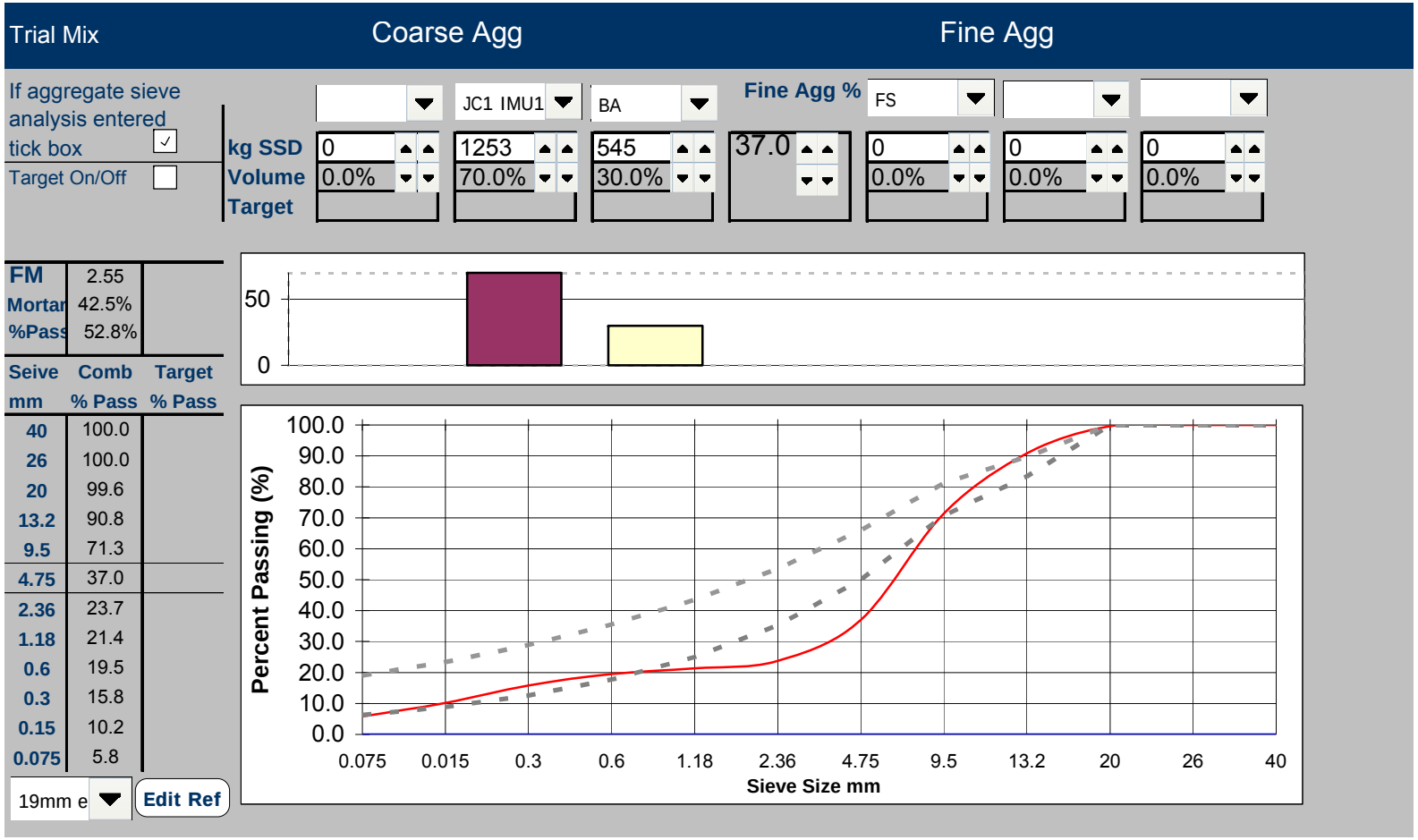
Blend 12


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1252
182
39.7
364
0
0
0.0%
70.0%
10.0%
20.0%
0.0%
0.0%
FM 2.39
Mortar 47.6%
%Pass 66.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.7
13.2 91.7
9.5 72.8
4.75 39.7
2.36 27.9
1.18 27.1
0.6 26.5
0.3 17.8
0.15 4.3
0.075 2.8
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

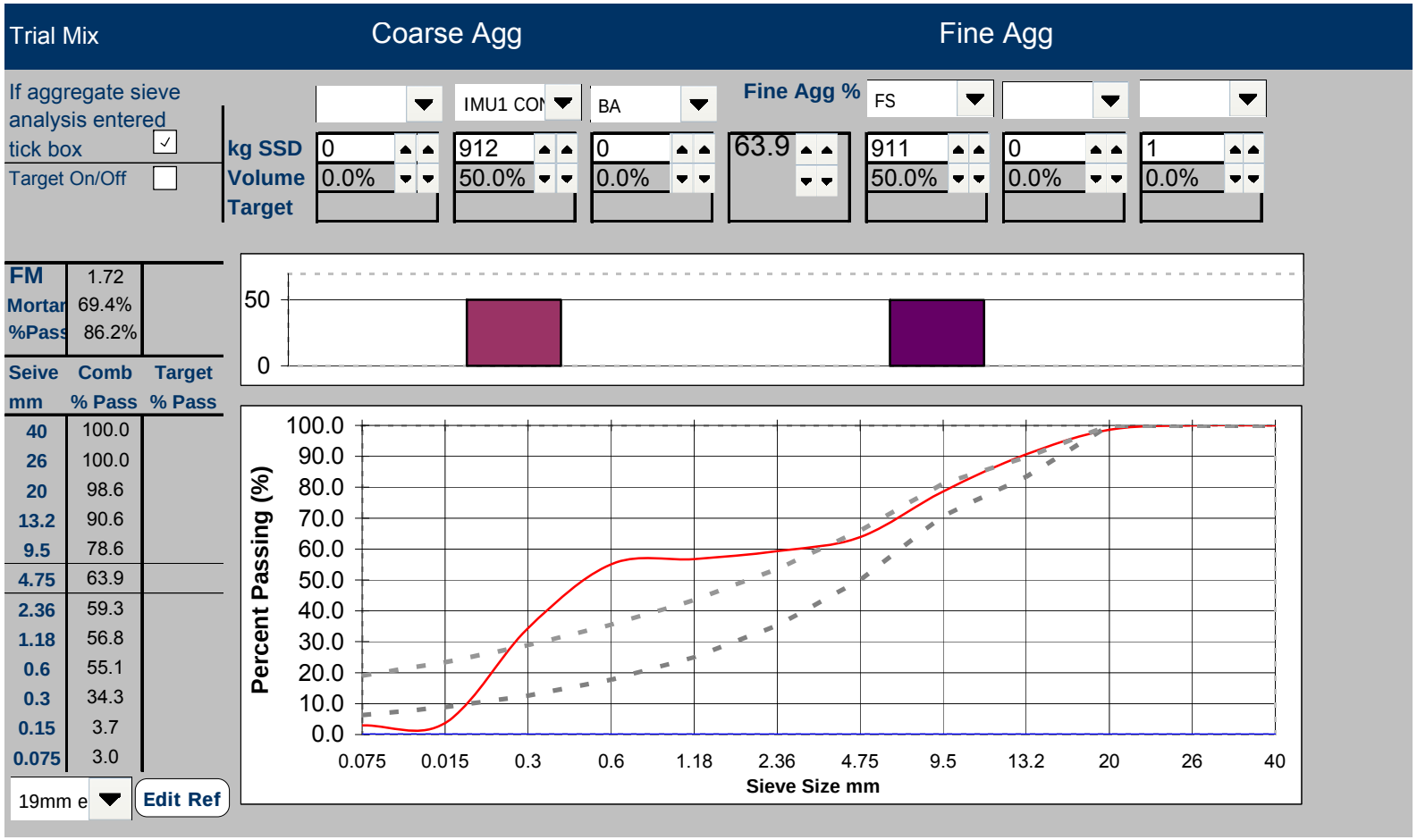
Blend 13


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1254
362
38.3
182
0
0
0.0%
70.1%
19.9%
10.0%
0.0%
0.0%
FM 2.47
Mortar 45.0%
%Pass 60.0%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.6
13.2 91.2
9.5 72.0
4.75 38.3
2.36 25.8
1.18 24.2
0.6 23.0
0.3 16.8
0.15 7.2
0.075 4.3
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

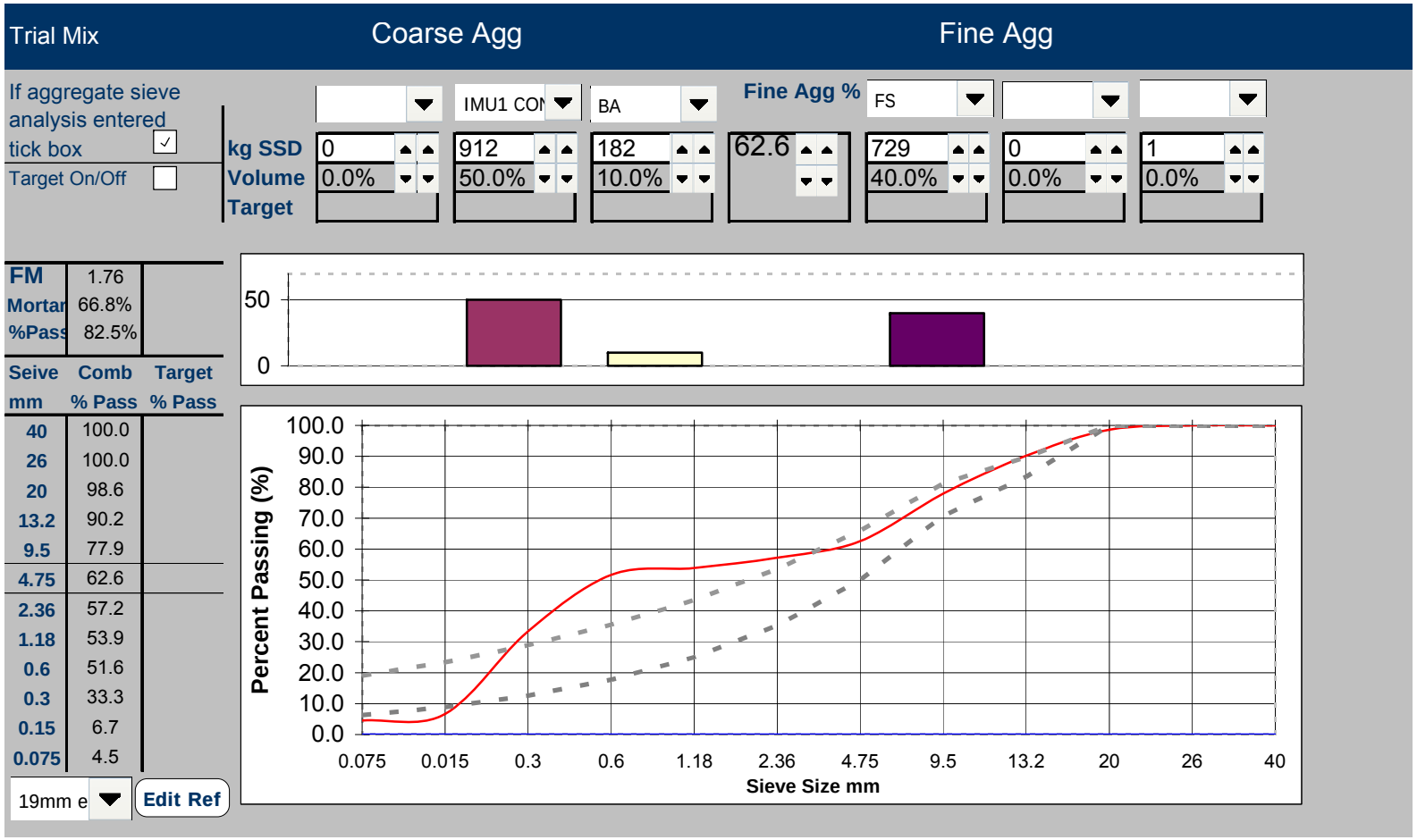
Blend 14


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
JC1 IMU1
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1253
545
37.0
0
0
0
0.0%
70.0%
30.0%
0.0%
0.0%
0.0%
FM 2.55
Mortar 42.5%
%Pass 52.8%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.6
13.2 90.8
9.5 71.3
4.75 37.0
2.36 23.7
1.18 21.4
0.6 19.5
0.3 15.8
0.15 10.2
0.075 5.8
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

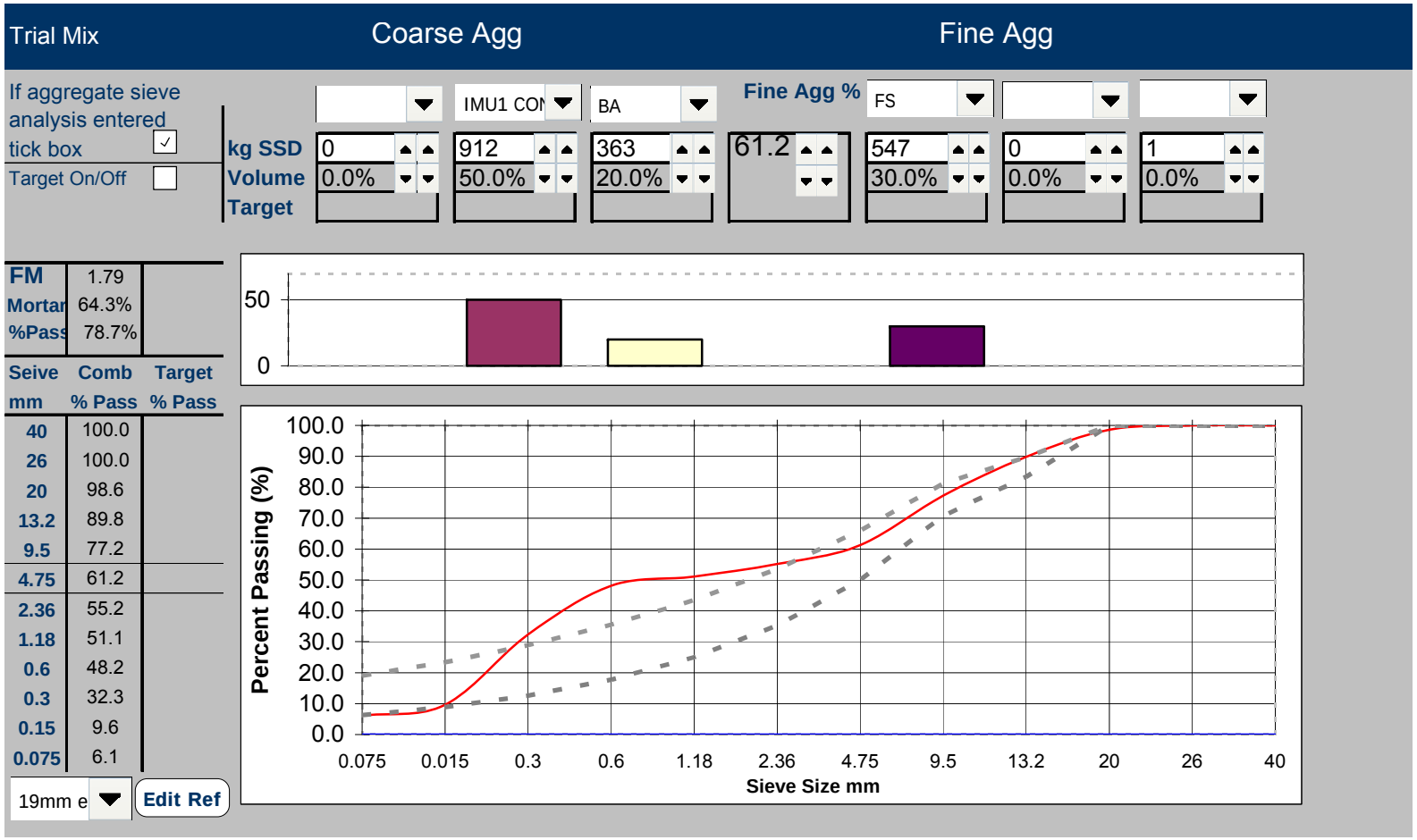
Blend 15


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
912
0
63.9
911
0
1
0.0%
50.0%
0.0%
50.0%
0.0%
0.0%
FM 1.72
Mortar 69.4%
%Pass 86.2%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.6
13.2 90.6
9.5 78.6
4.75 63.9
2.36 59.3
1.18 56.8
0.6 55.1
0.3 34.3
0.15 3.7
0.075 3.0
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

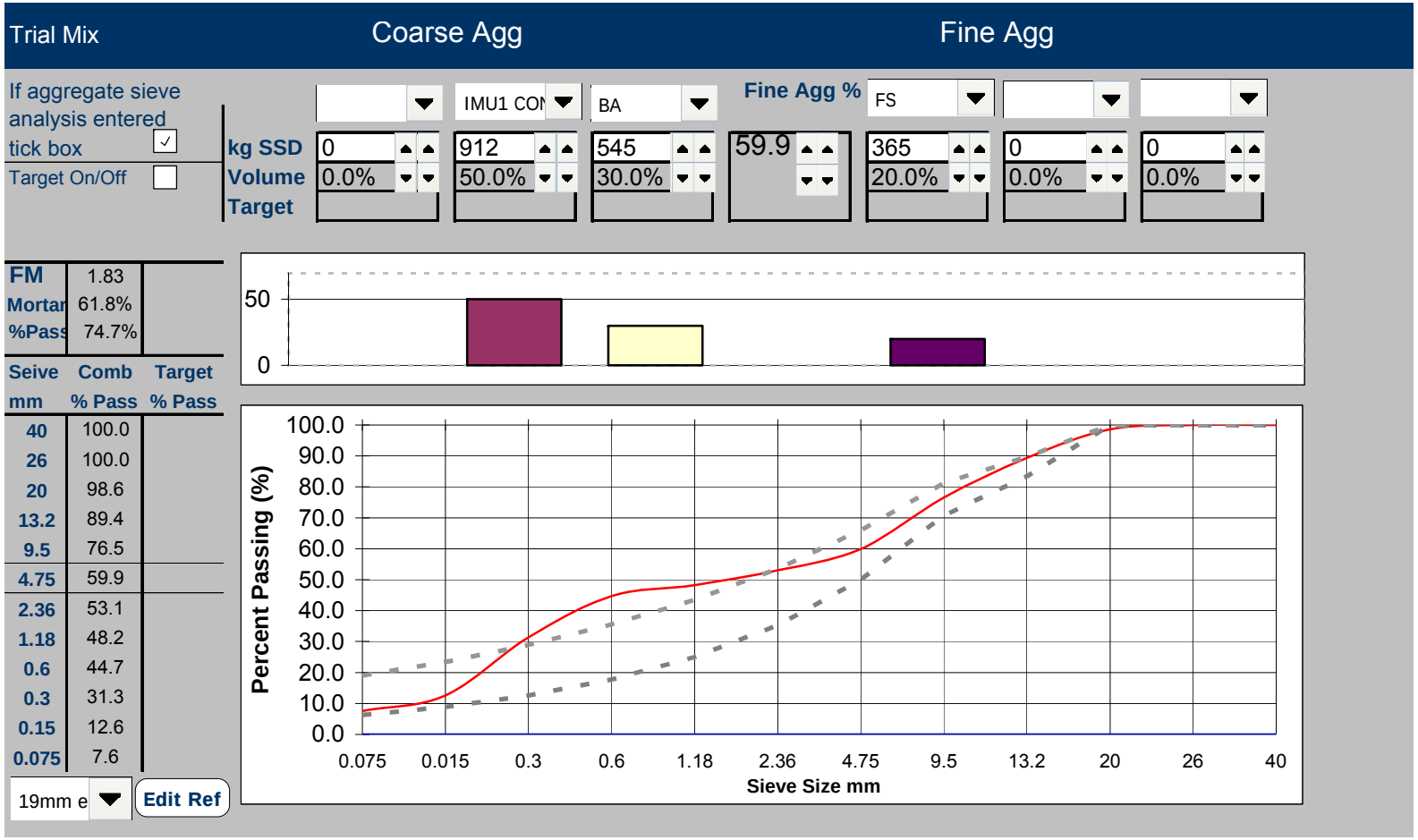
Blend 16


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
912
182
62.6
729
0
1
0.0%
50.0%
10.0%
40.0%
0.0%
0.0%
FM 1.76
Mortar 66.8%
%Pass 82.5%
50
0
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.6
13.2 90.2
9.5 77.9
4.75 62.6
2.36 57.2
1.18 53.9
0.6 51.6
0.3 33.3
0.15 6.7
0.075 4.5
19mm e
Edit Ref
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

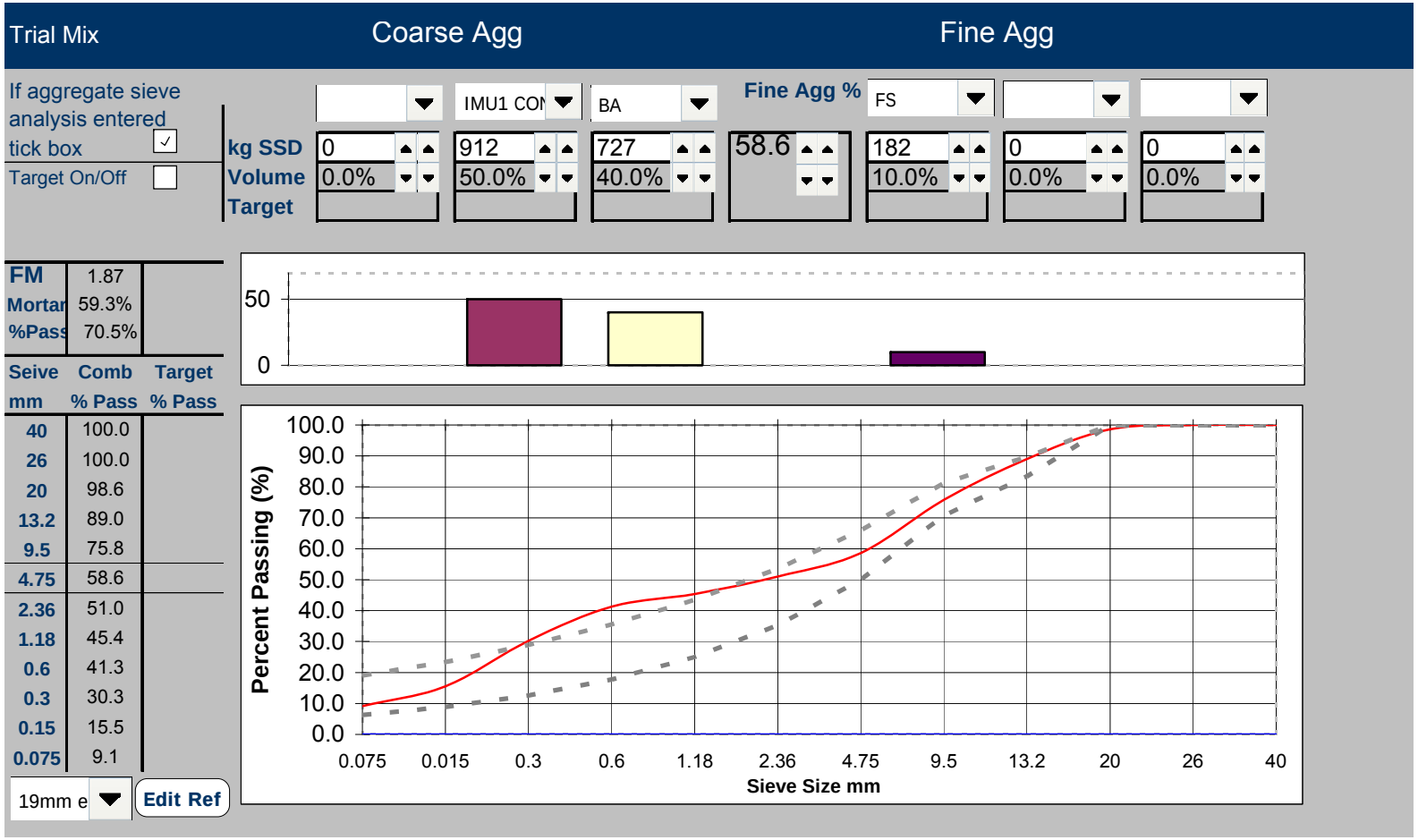
Blend 17


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
912
363
61.2
547
0
1
0.0%
50.0%
20.0%
30.0%
0.0%
0.0%
FM 1.79
Mortar 64.3%
%Pass 78.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.6
13.2 89.8
9.5 77.2
4.75 61.2
2.36 55.2
1.18 51.1
0.6 48.2
0.3 32.3
0.15 9.6
0.075 6.1
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

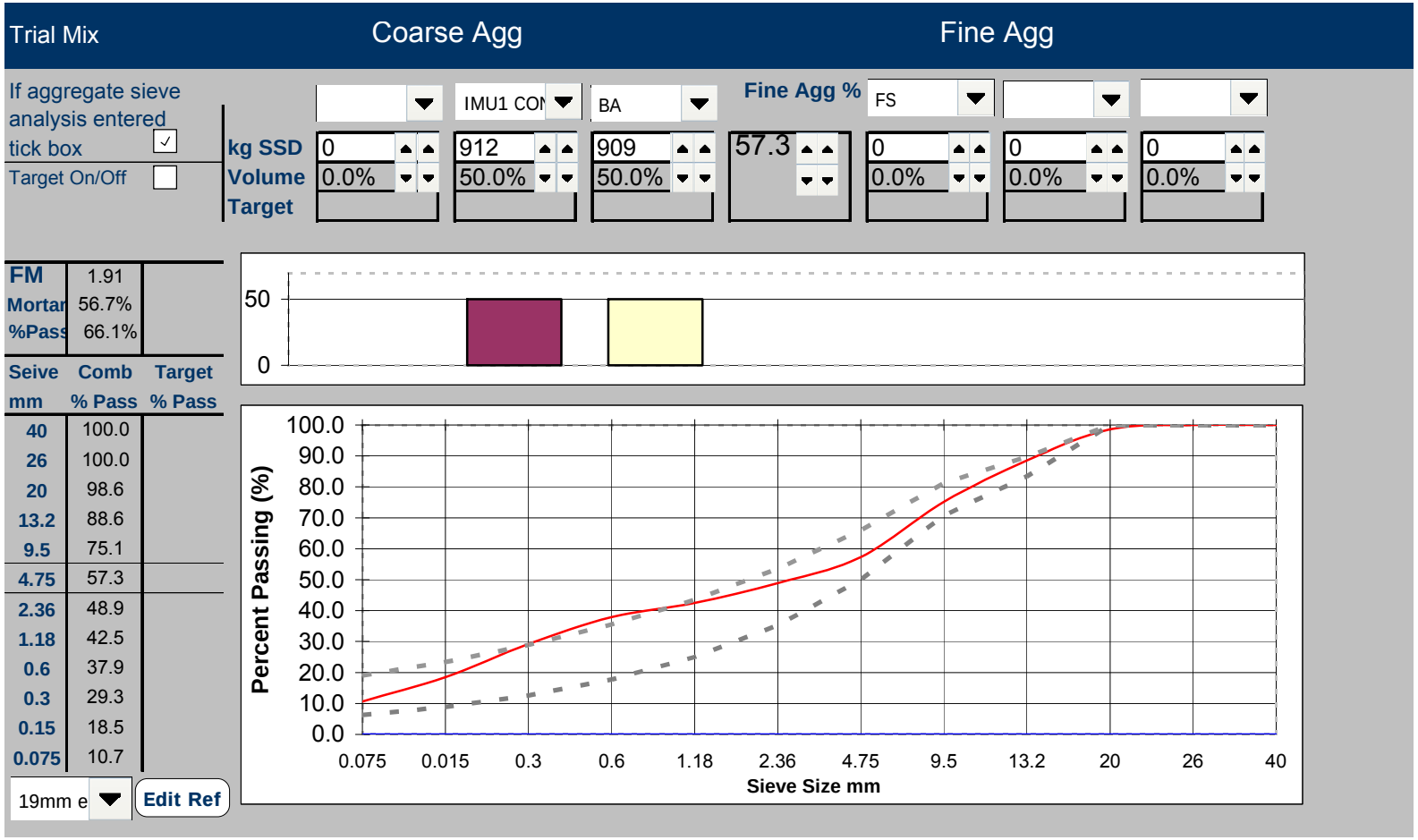
Blend 18


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
912
545
59.9
365
0
0
0.0%
50.0%
30.0%
20.0%
0.0%
0.0%
FM 1.83
Mortar 61.8%
%Pass 74.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.6
13.2 89.4
9.5 76.5
4.75 59.9
2.36 53.1
1.18 48.2
0.6 44.7
0.3 31.3
0.15 12.6
0.075 7.6
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

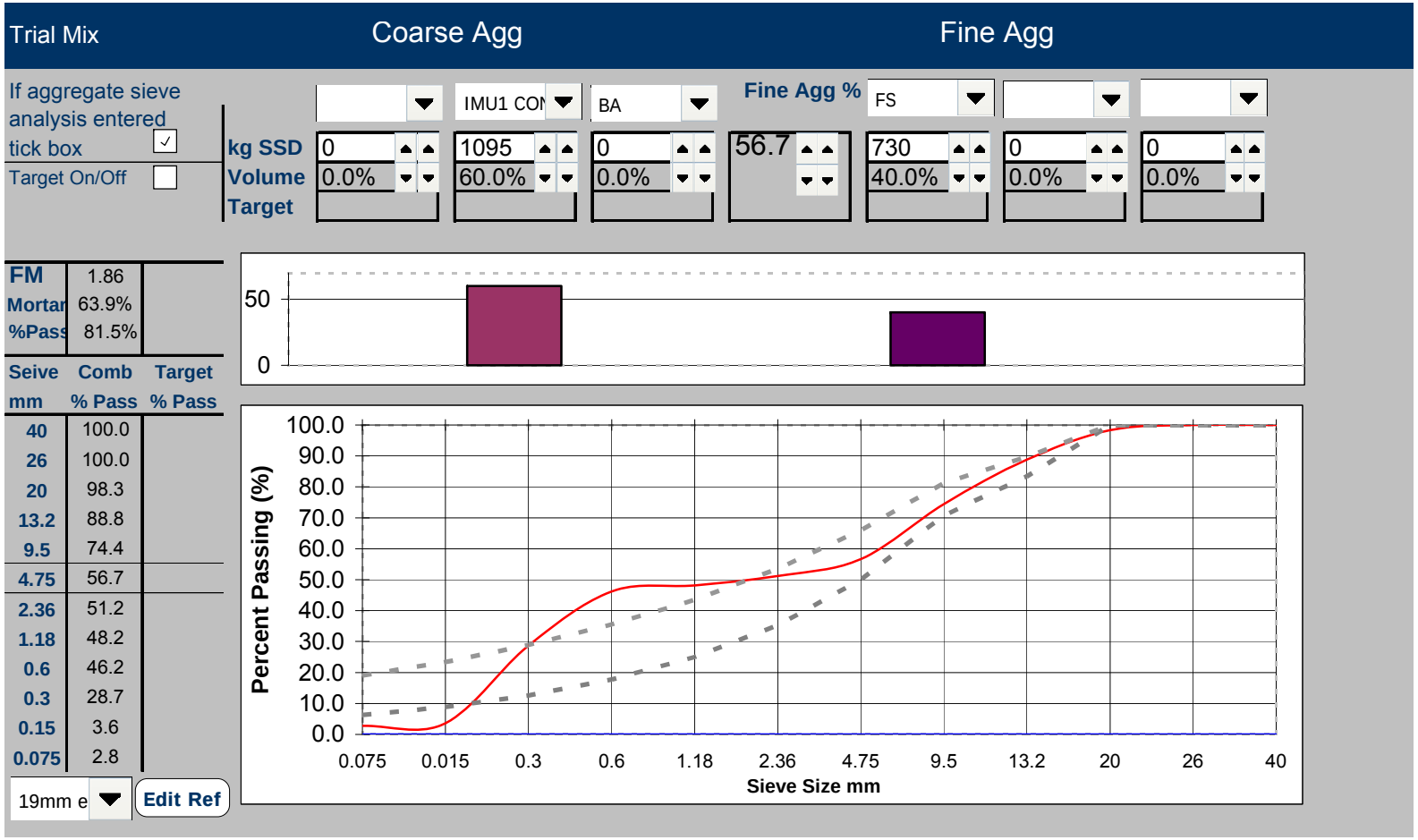
Blend 19


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
912
727
58.6
182
0
0
0.0%
50.0%
40.0%
10.0%
0.0%
0.0%
FM 1.87
Mortar 59.3%
%Pass 70.5%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.6
13.2 89.0
9.5 75.8
4.75 58.6
2.36 51.0
1.18 45.4
0.6 41.3
0.3 30.3
0.15 15.5
0.075 9.1
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

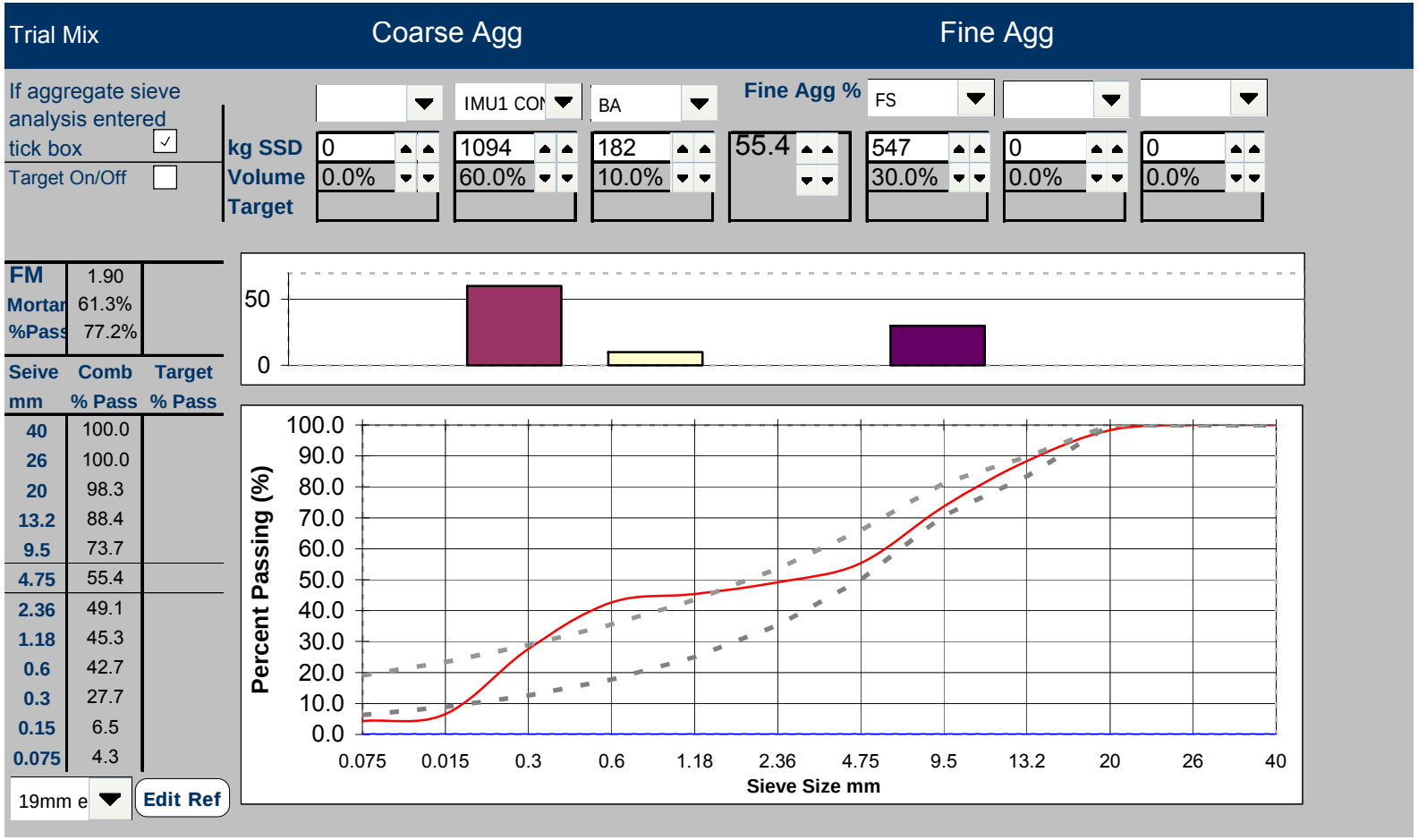
Blend 20


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
912
909
57.3
0
0
0
0.0%
50.0%
50.0%
0.0%
0.0%
0.0%
FM 1.91
Mortar 56.7%
%Pass 66.1%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.6
13.2 88.6
9.5 75.1
4.75 57.3
2.36 48.9
1.18 42.5
0.6 37.9
0.3 29.3
0.15 18.5
0.075 10.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

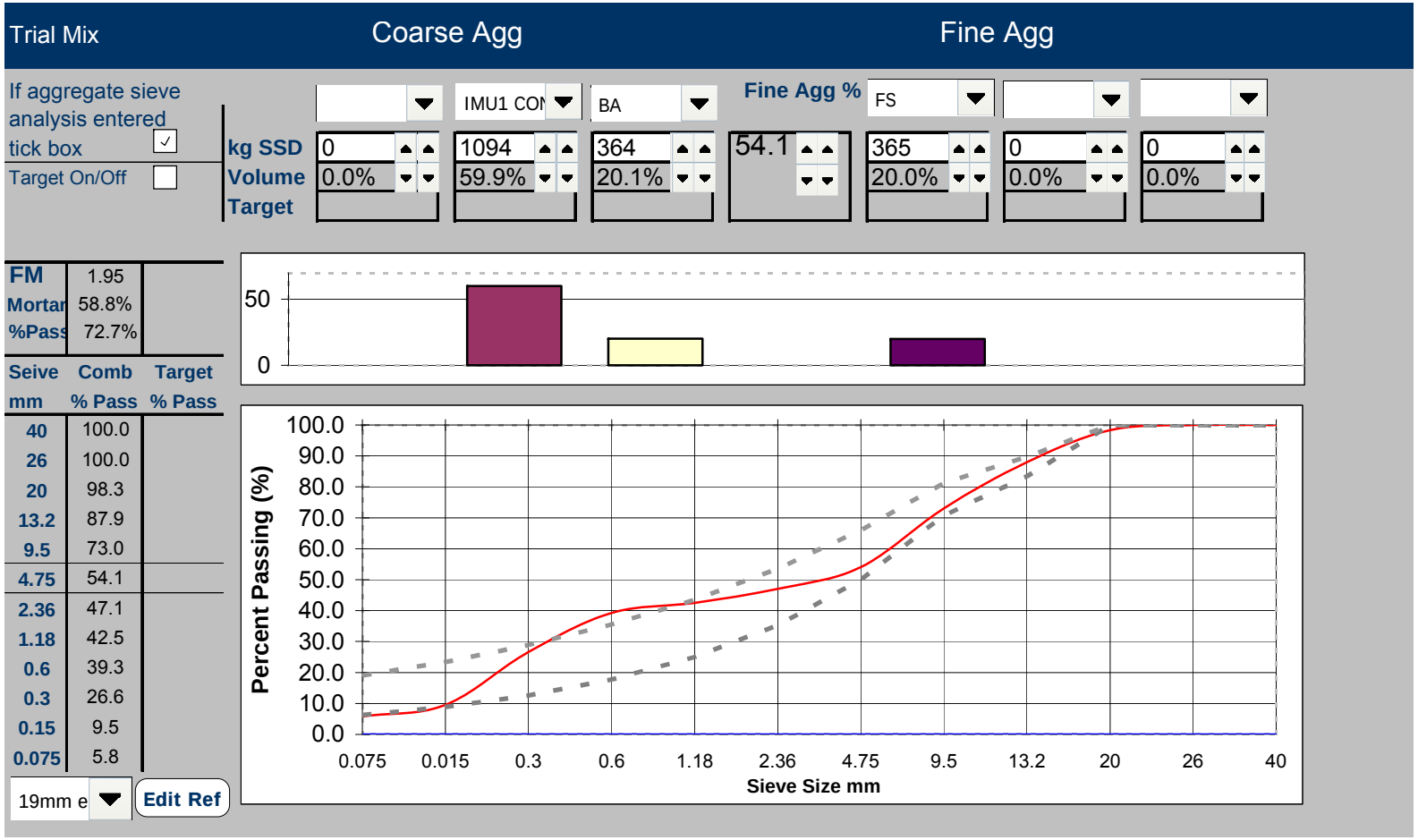
Blend 21


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1095
0
56.7
730
0
0
0.0%
60.0%
0.0%
40.0%
0.0%
0.0%
FM 1.86
Mortar 63.9%
%Pass 81.5%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.3
13.2 88.8
9.5 74.4
4.75 56.7
2.36 51.2
1.18 48.2
0.6 46.2
0.3 28.7
0.15 3.6
0.075 2.8
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

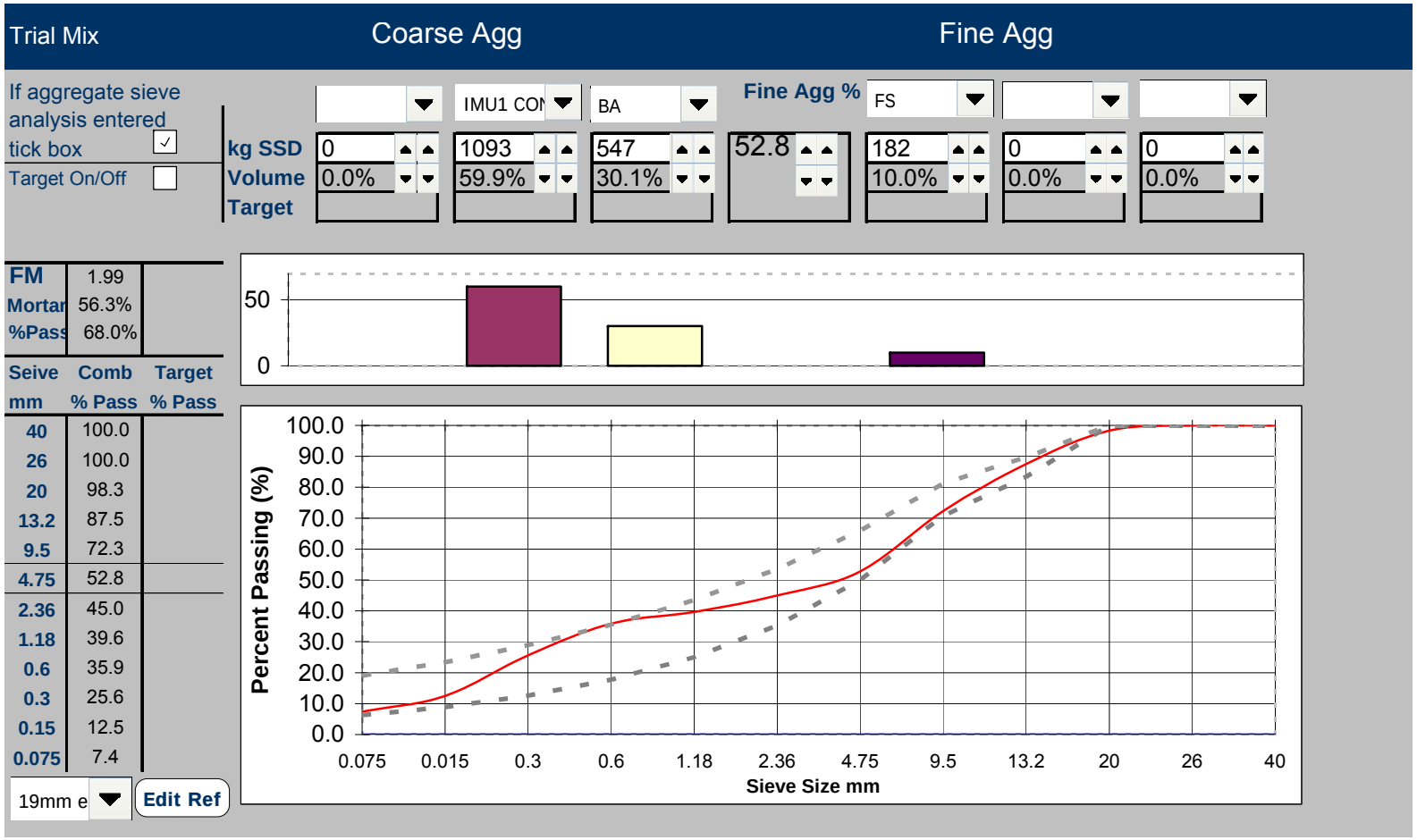
Blend 22


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1094
182
55.4
547
0
0
0.0%
60.0%
10.0%
30.0%
0.0%
0.0%
FM 1.90
Mortar 61.3%
%Pass 77.2%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.3
13.2 88.4
9.5 73.7
4.75 55.4
2.36 49.1
1.18 45.3
0.6 42.7
0.3 27.7
0.15 6.5
0.075 4.3
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

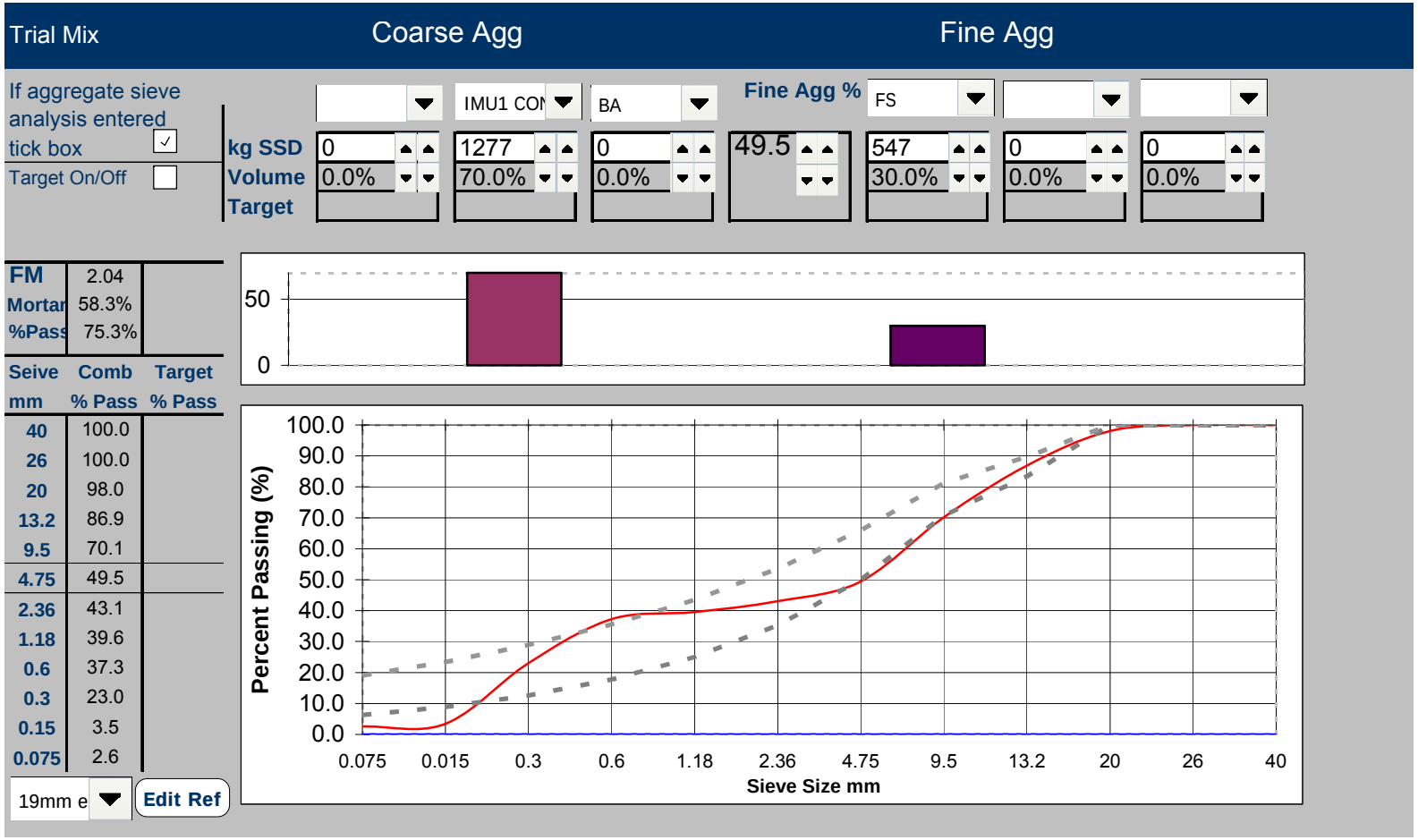
Blend 23


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1094
364
54.1
365
0
0
0.0%
59.9%
20.1%
20.0%
0.0%
0.0%
FM 1.95
Mortar 58.8%
%Pass 72.7%
50
0
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.3
13.2 87.9
9.5 73.0
4.75 54.1
2.36 47.1
1.18 42.5
0.6 39.3
0.3 26.6
0.15 9.5
0.075 5.8
19mm e
Edit Ref
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

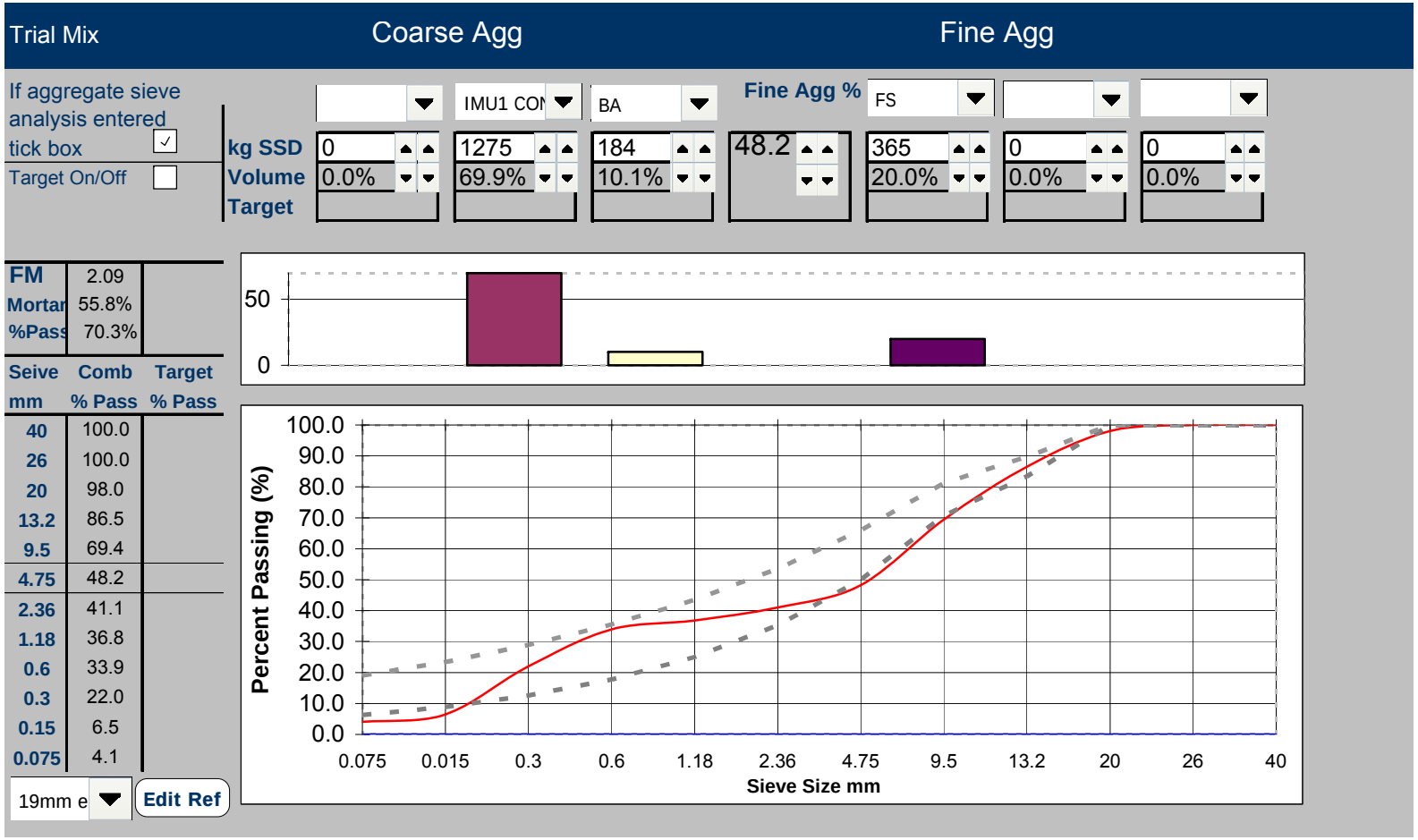
Blend 24


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1093
547
52.8
182
0
0
0.0%
59.9%
30.1%
10.0%
0.0%
0.0%
FM 1.99
Mortar 56.3%
%Pass 68.0%
50
0
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.3
13.2 87.5
9.5 72.3
4.75 52.8
2.36 45.0
1.18 39.6
0.6 35.9
0.3 25.6
0.15 12.5
0.075 7.4
19mm e
Edit Ref
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

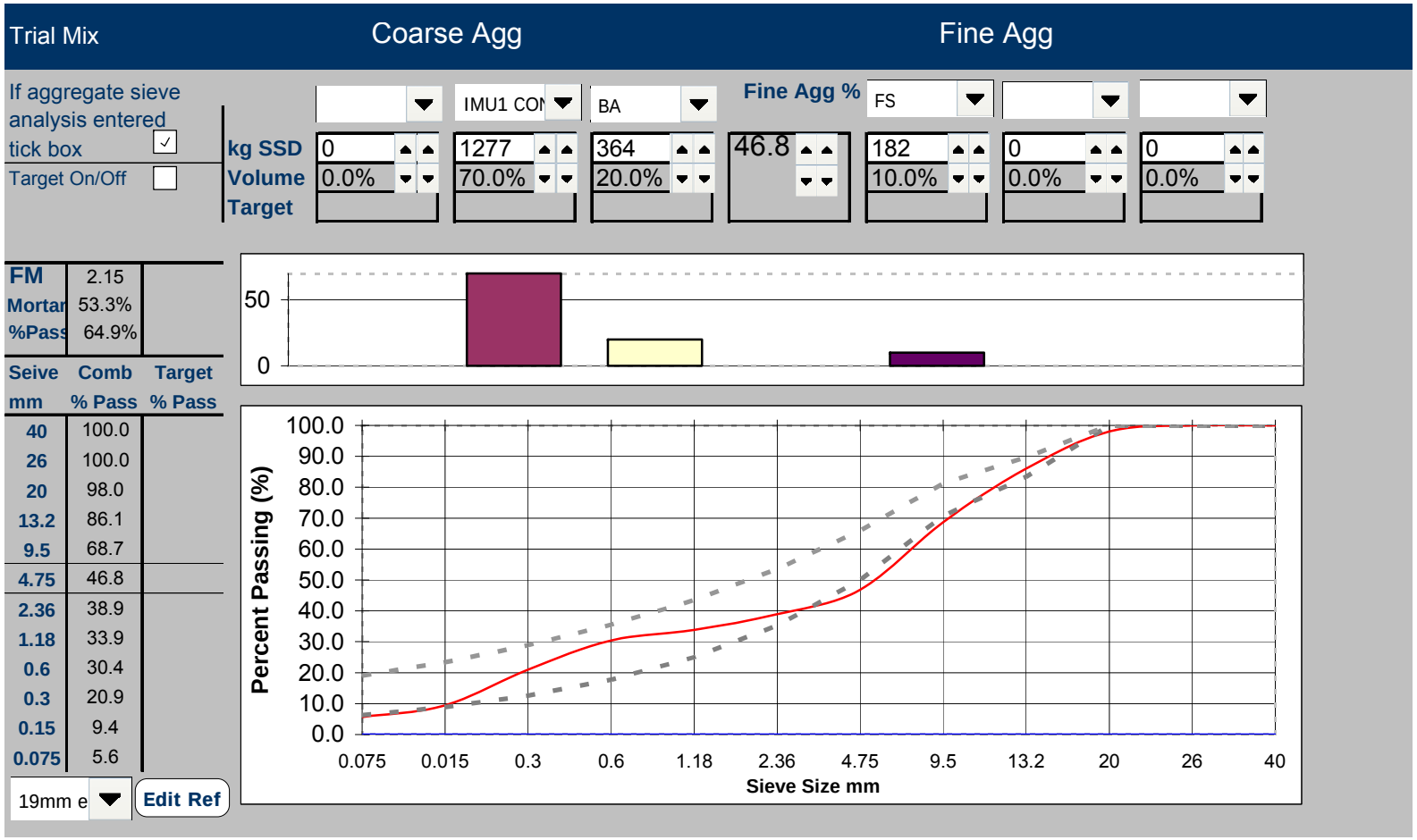
Blend 25


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1277
0
49.5
547
0
0
0.0%
70.0%
0.0%
30.0%
0.0%
0.0%
FM 2.04
Mortar 58.3%
%Pass 75.3%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.0
13.2 86.9
9.5 70.1
4.75 49.5
2.36 43.1
1.18 39.6
0.6 37.3
0.3 23.0
0.15 3.5
0.075 2.6
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

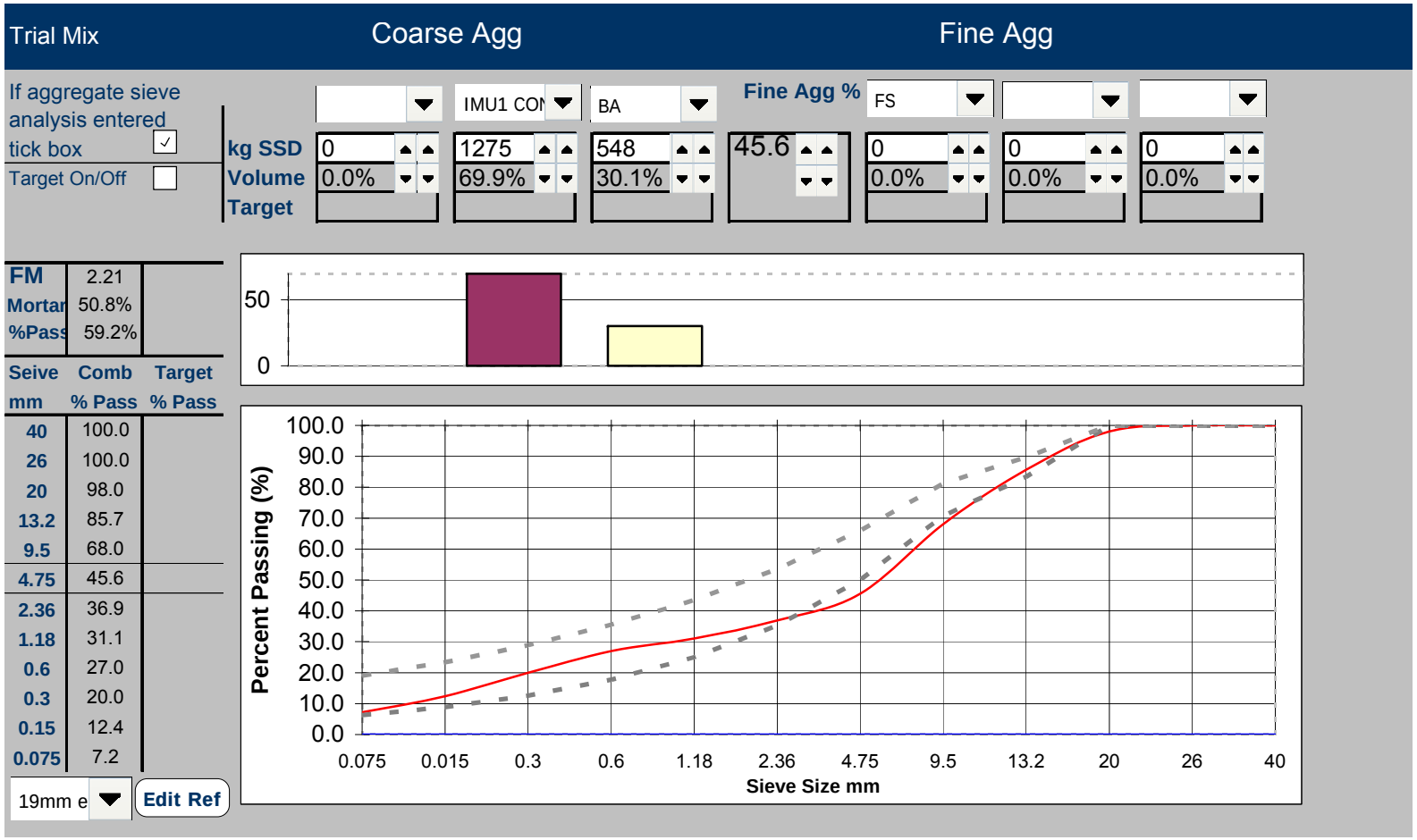
Blend 27


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1275
184
48.2
365
0
0
0.0%
69.9%
10.1%
20.0%
0.0%
0.0%
FM 2.09
Mortar 55.8%
%Pass 70.3%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.0
13.2 86.5
9.5 69.4
4.75 48.2
2.36 41.1
1.18 36.8
0.6 33.9
0.3 22.0
0.15 6.5
0.075 4.1
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

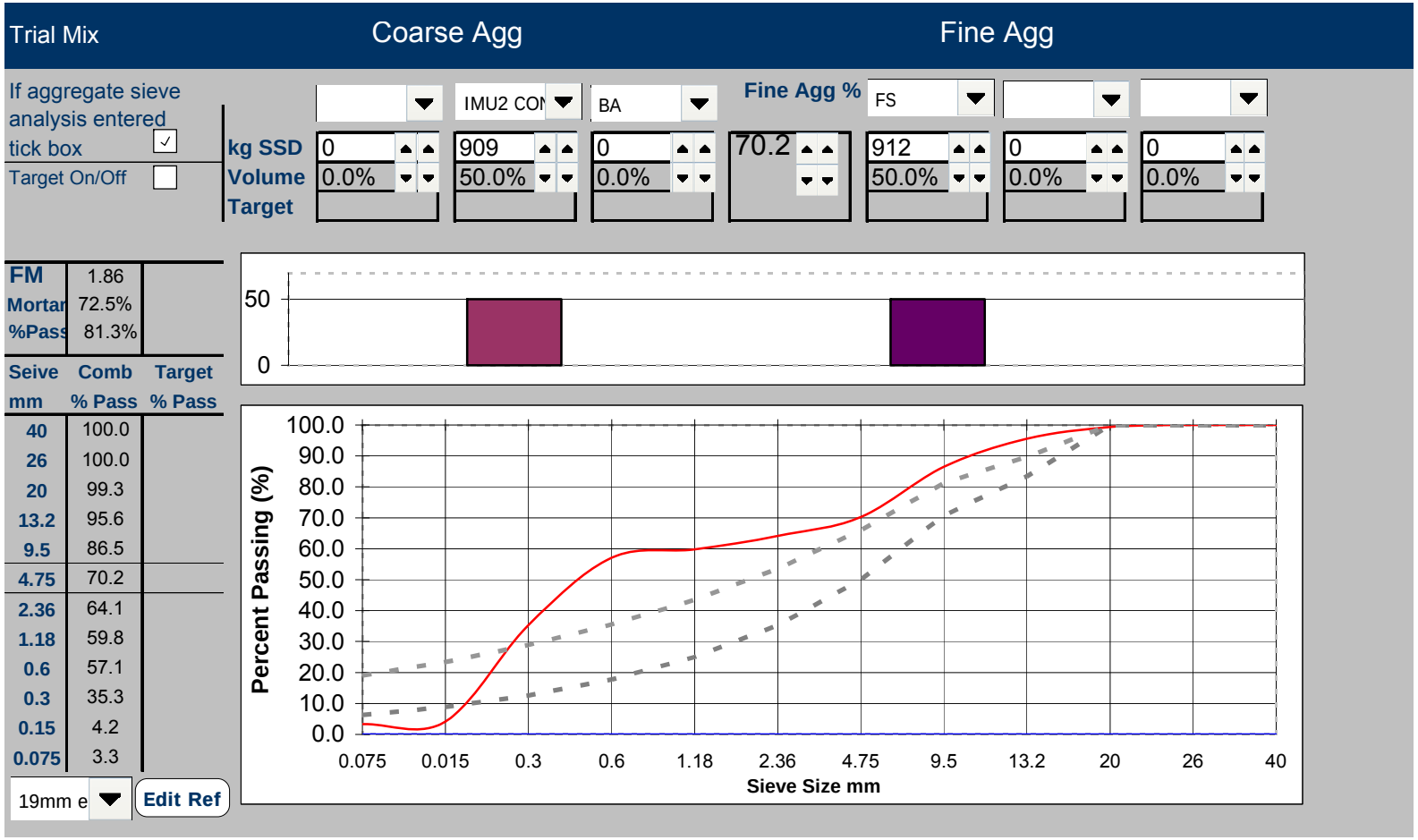
Blend 28


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1277
364
46.8
182
0
0
0.0%
70.0%
20.0%
10.0%
0.0%
0.0%
FM 2.15
Mortar 53.3%
%Pass 64.9%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.0
13.2 86.1
9.5 68.7
4.75 46.8
2.36 38.9
1.18 33.9
0.6 30.4
0.3 20.9
0.15 9.4
0.075 5.6
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

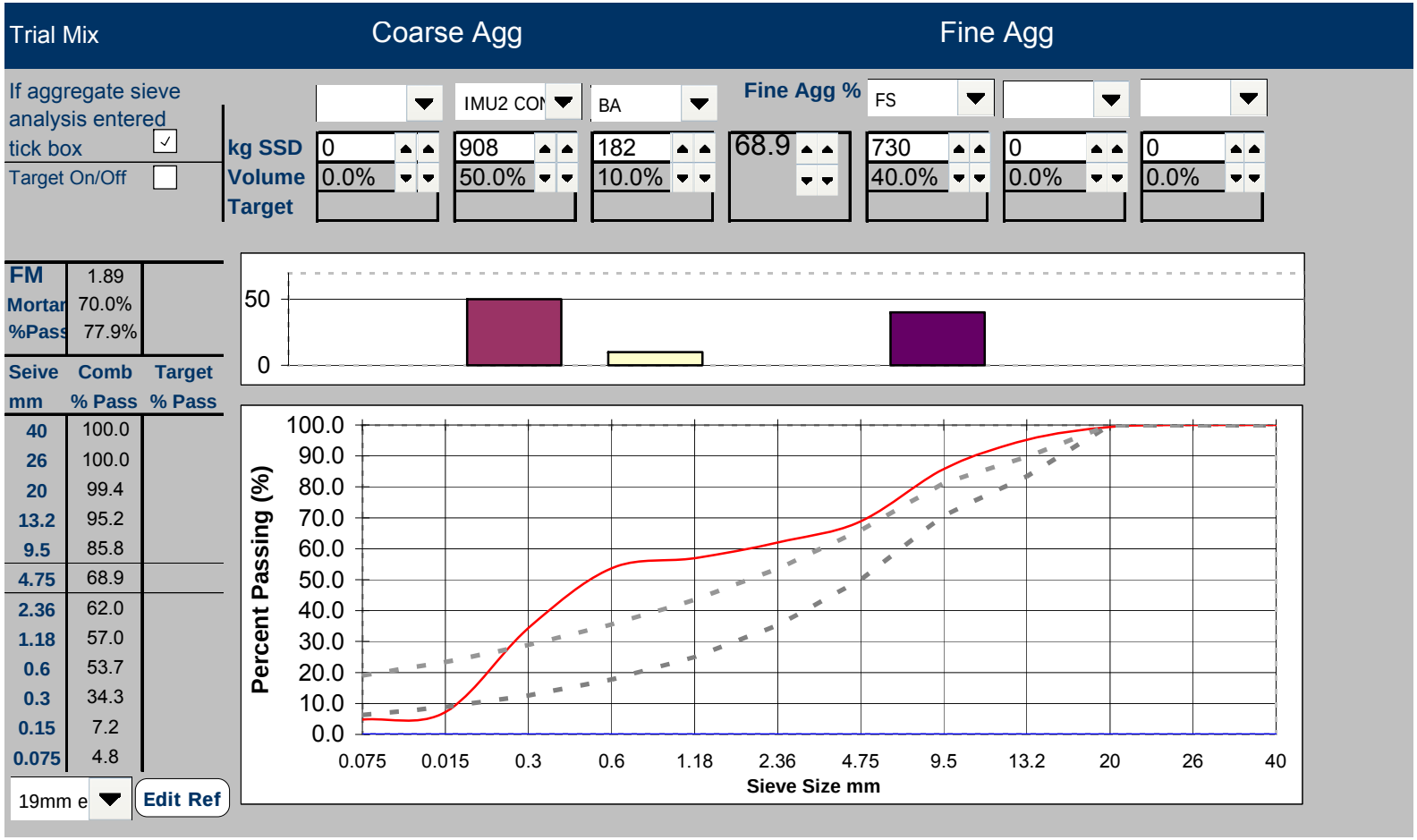
Blend 29


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU1 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1275
548
45.6
0
0
0
0.0%
69.9%
30.1%
0.0%
0.0%
0.0%
FM 2.21
Mortar 50.8%
%Pass 59.2%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 98.0
13.2 85.7
9.5 68.0
4.75 45.6
2.36 36.9
1.18 31.1
0.6 27.0
0.3 20.0
0.15 12.4
0.075 7.2
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

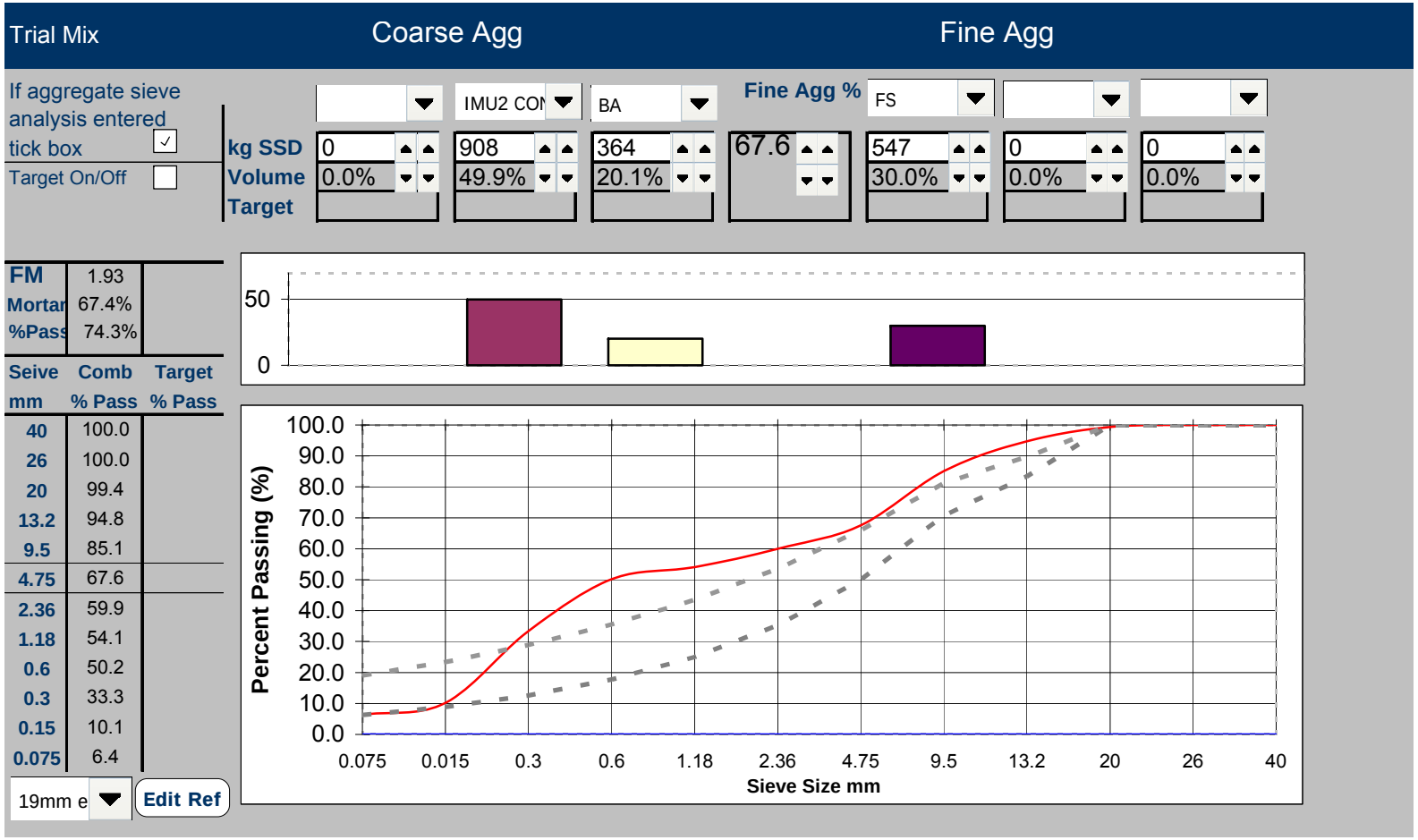
Blend 30


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
909
0
70.2
912
0
0
0.0%
50.0%
0.0%
50.0%
0.0%
0.0%
FM 1.86
Mortar 72.5%
%Pass 81.3%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.3
13.2 95.6
9.5 86.5
4.75 70.2
2.36 64.1
1.18 59.8
0.6 57.1
0.3 35.3
0.15 4.2
0.075 3.3
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

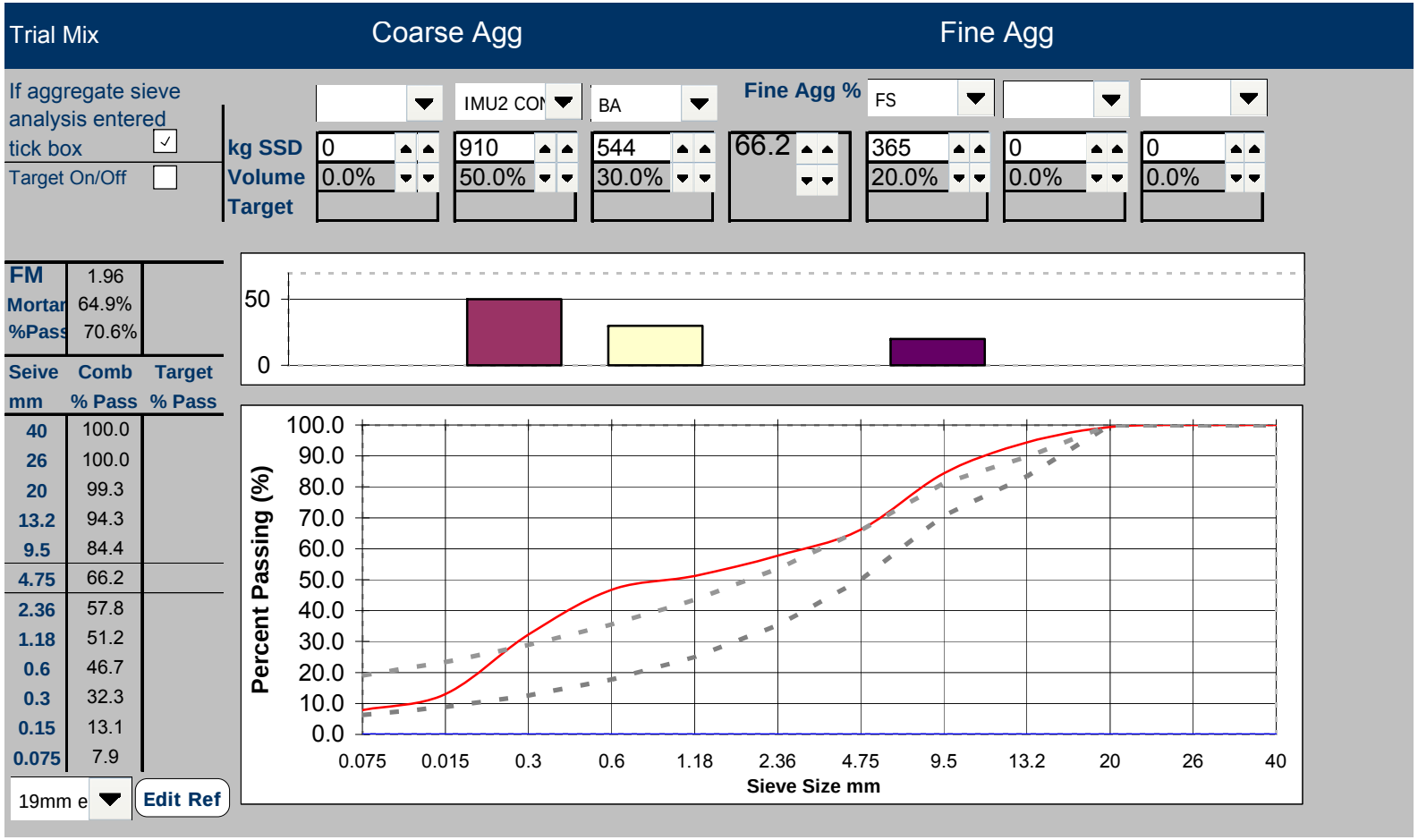
Blend 31


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
908
182
68.9
730
0
0
0.0%
50.0%
10.0%
40.0%
0.0%
0.0%
FM 1.89
Mortar 70.0%
%Pass 77.9%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.4
13.2 95.2
9.5 85.8
4.75 68.9
2.36 62.0
1.18 57.0
0.6 53.7
0.3 34.3
0.15 7.2
0.075 4.8
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

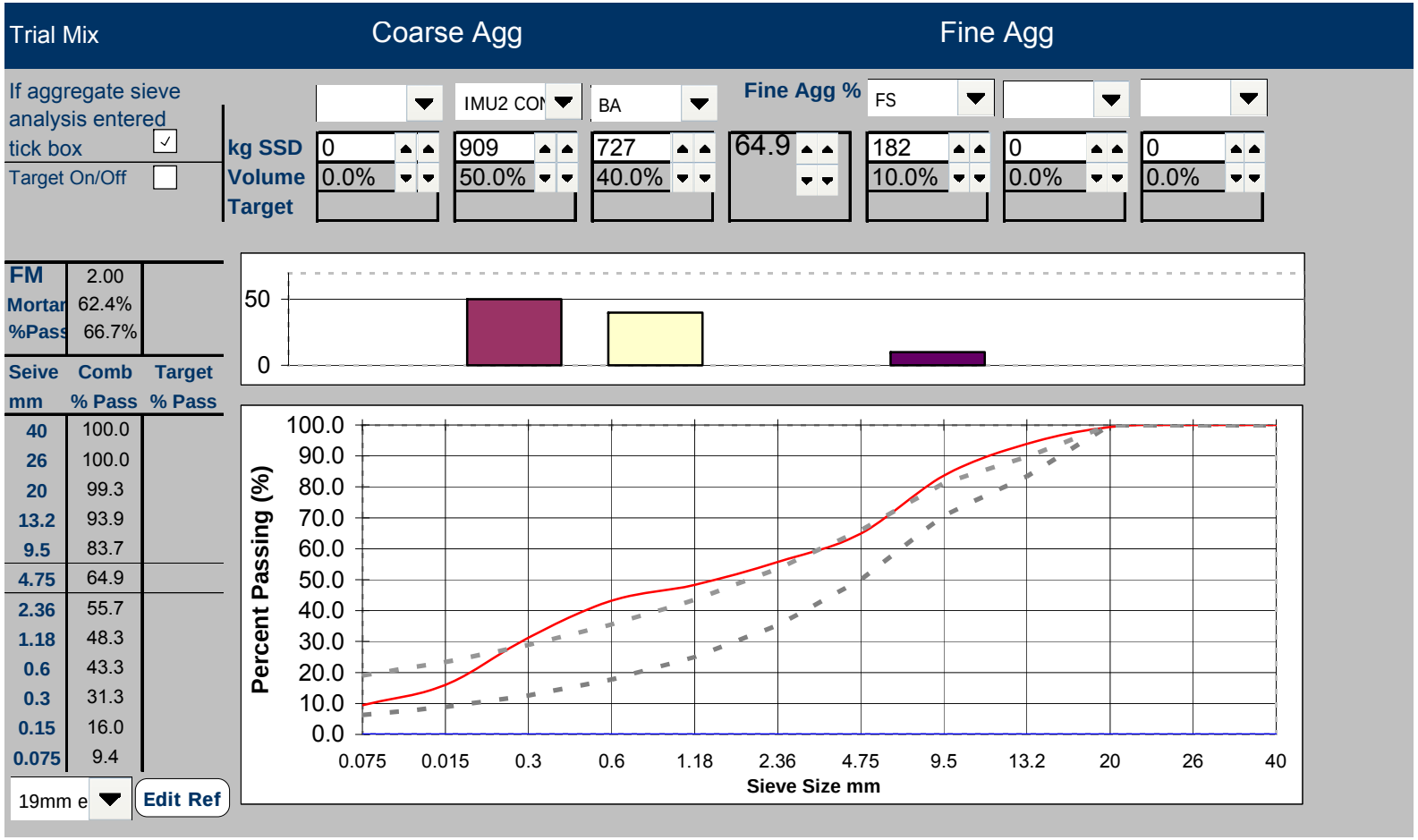
Blend 32


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
908
364
67.6
547
0
0
0.0%
49.9%
20.1%
30.0%
0.0%
0.0%
FM 1.93
Mortar 67.4%
%Pass 74.3%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.4
13.2 94.8
9.5 85.1
4.75 67.6
2.36 59.9
1.18 54.1
0.6 50.2
0.3 33.3
0.15 10.1
0.075 6.4
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

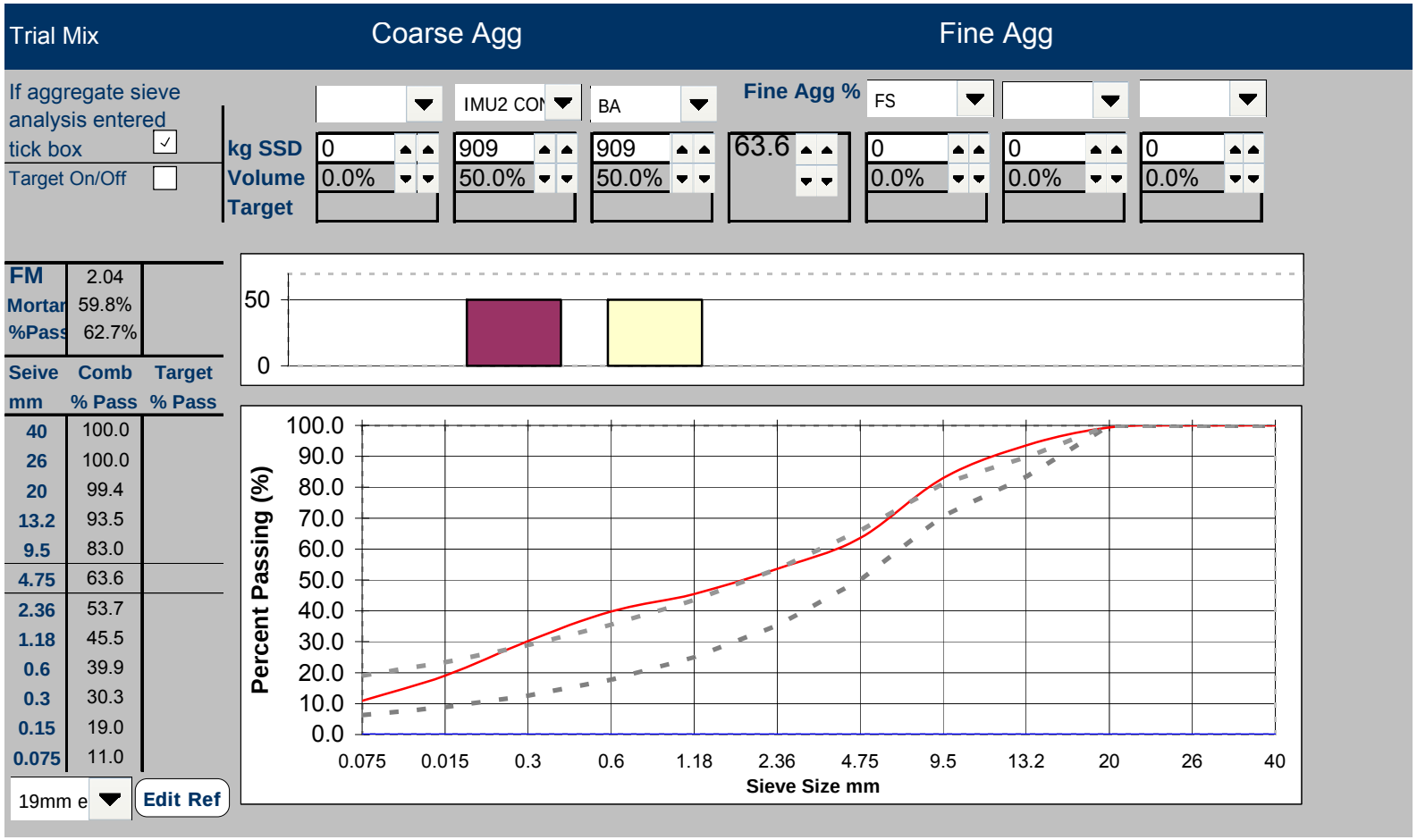
Blend 33


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
910
544
66.2
365
0
0
0.0%
50.0%
30.0%
20.0%
0.0%
0.0%
FM 1.96
Mortar 64.9%
%Pass 70.6%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.3
13.2 94.3
9.5 84.4
4.75 66.2
2.36 57.8
1.18 51.2
0.6 46.7
0.3 32.3
0.15 13.1
0.075 7.9
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

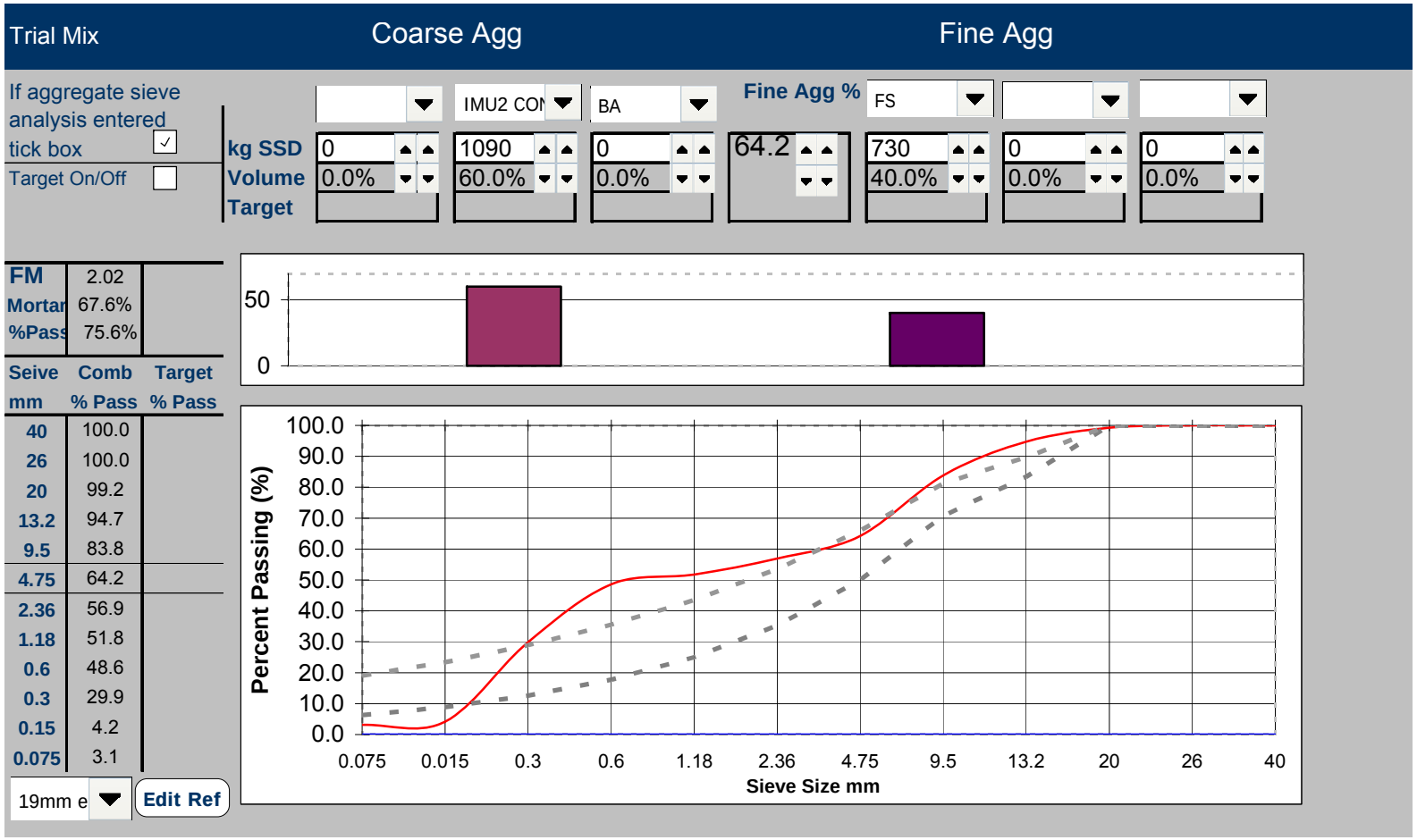
Blend 34


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
909
727
64.9
182
0
0
0.0%
50.0%
40.0%
10.0%
0.0%
0.0%
FM 2.00
Mortar 62.4%
%Pass 66.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.3
13.2 93.9
9.5 83.7
4.75 64.9
2.36 55.7
1.18 48.3
0.6 43.3
0.3 31.3
0.15 16.0
0.075 9.4
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

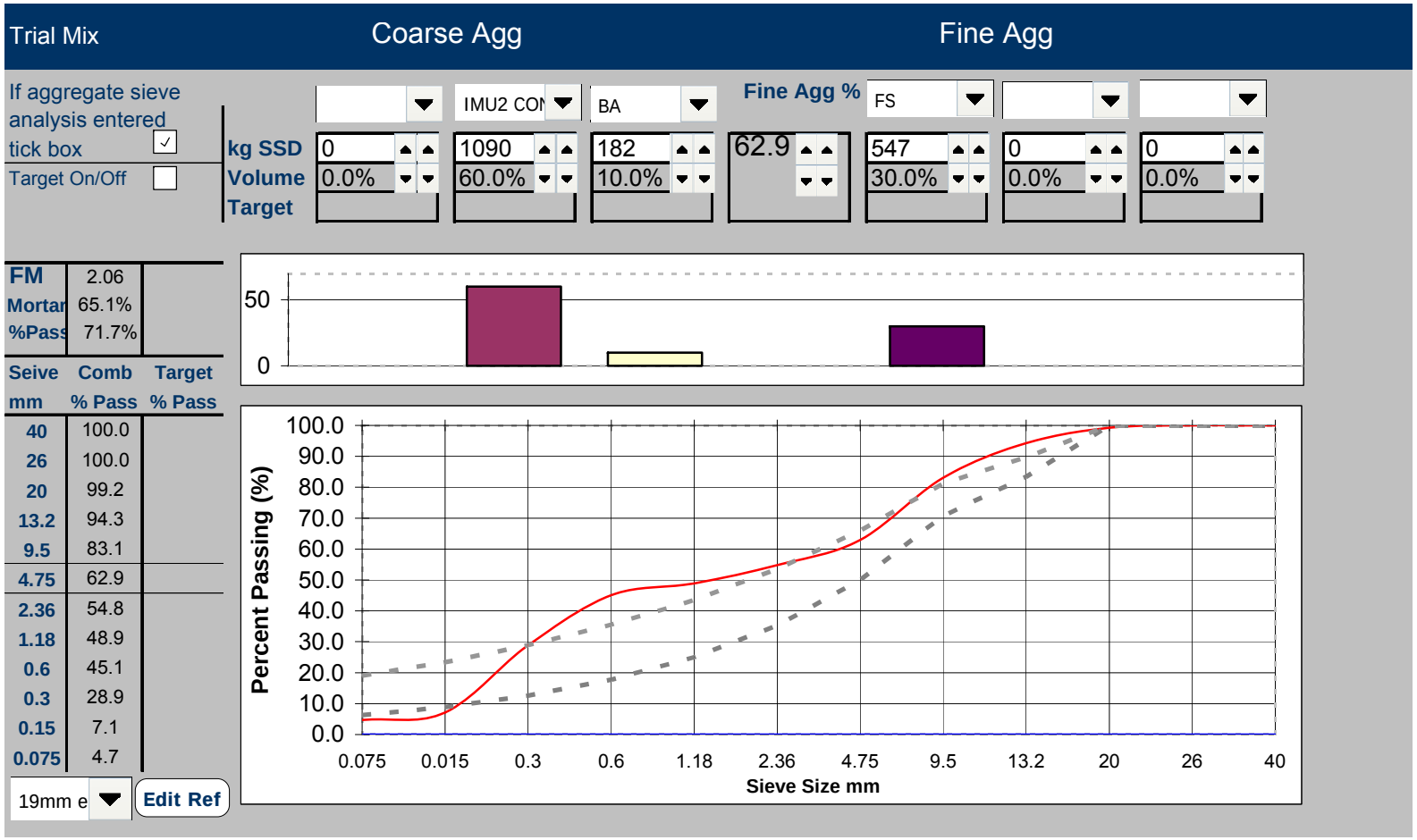
Blend 35


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
909
909
63.6
0
0
0
0.0%
50.0%
50.0%
0.0%
0.0%
0.0%
FM 2.04
Mortar 59.8%
%Pass 62.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.4
13.2 93.5
9.5 83.0
4.75 63.6
2.36 53.7
1.18 45.5
0.6 39.9
0.3 30.3
0.15 19.0
0.075 11.0
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

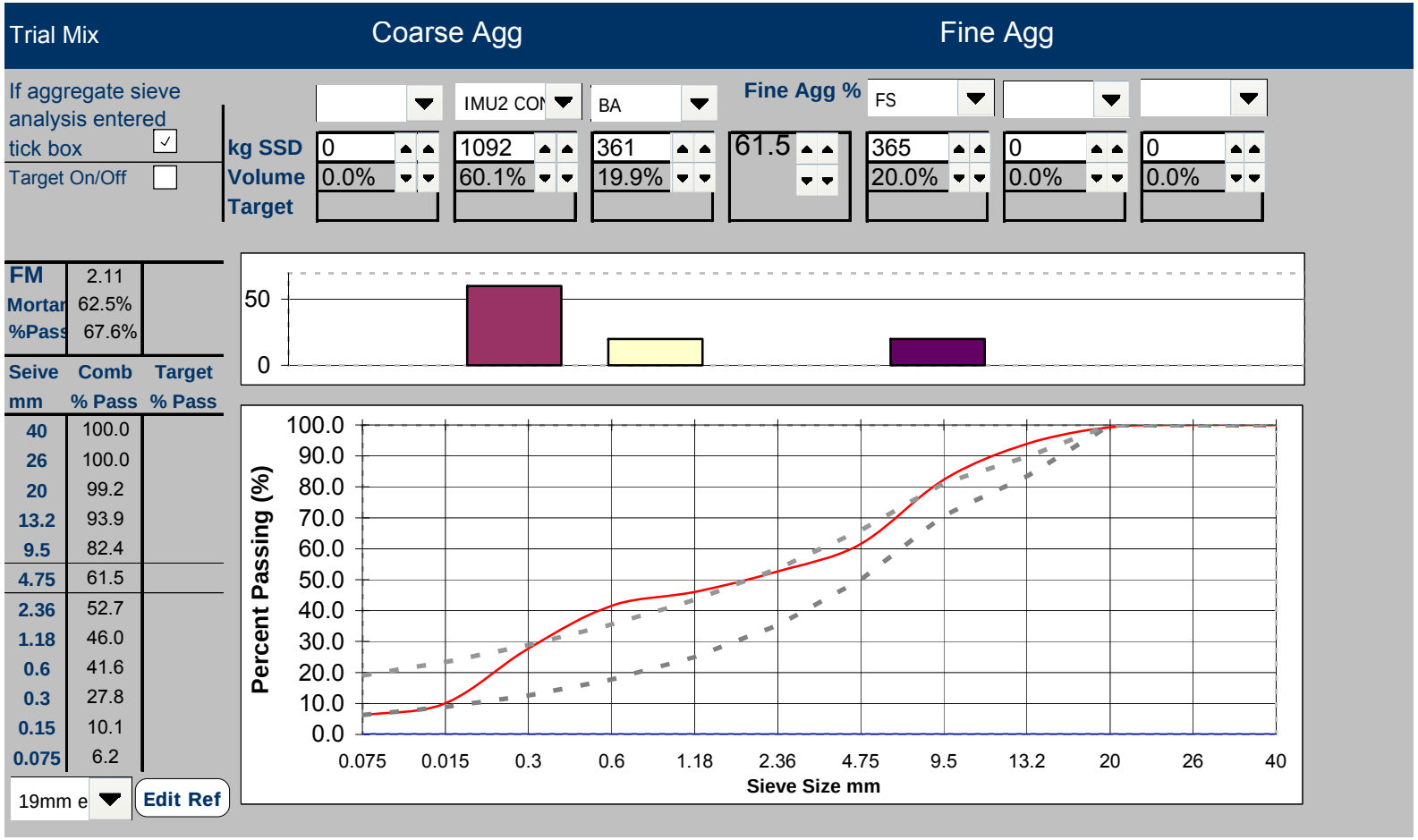
Blend 36


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1090
0
64.2
730
0
0
0.0%
60.0%
0.0%
40.0%
0.0%
0.0%
FM 2.02
Mortar 67.6%
%Pass 75.6%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.2
13.2 94.7
9.5 83.8
4.75 64.2
2.36 56.9
1.18 51.8
0.6 48.6
0.3 29.9
0.15 4.2
0.075 3.1
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

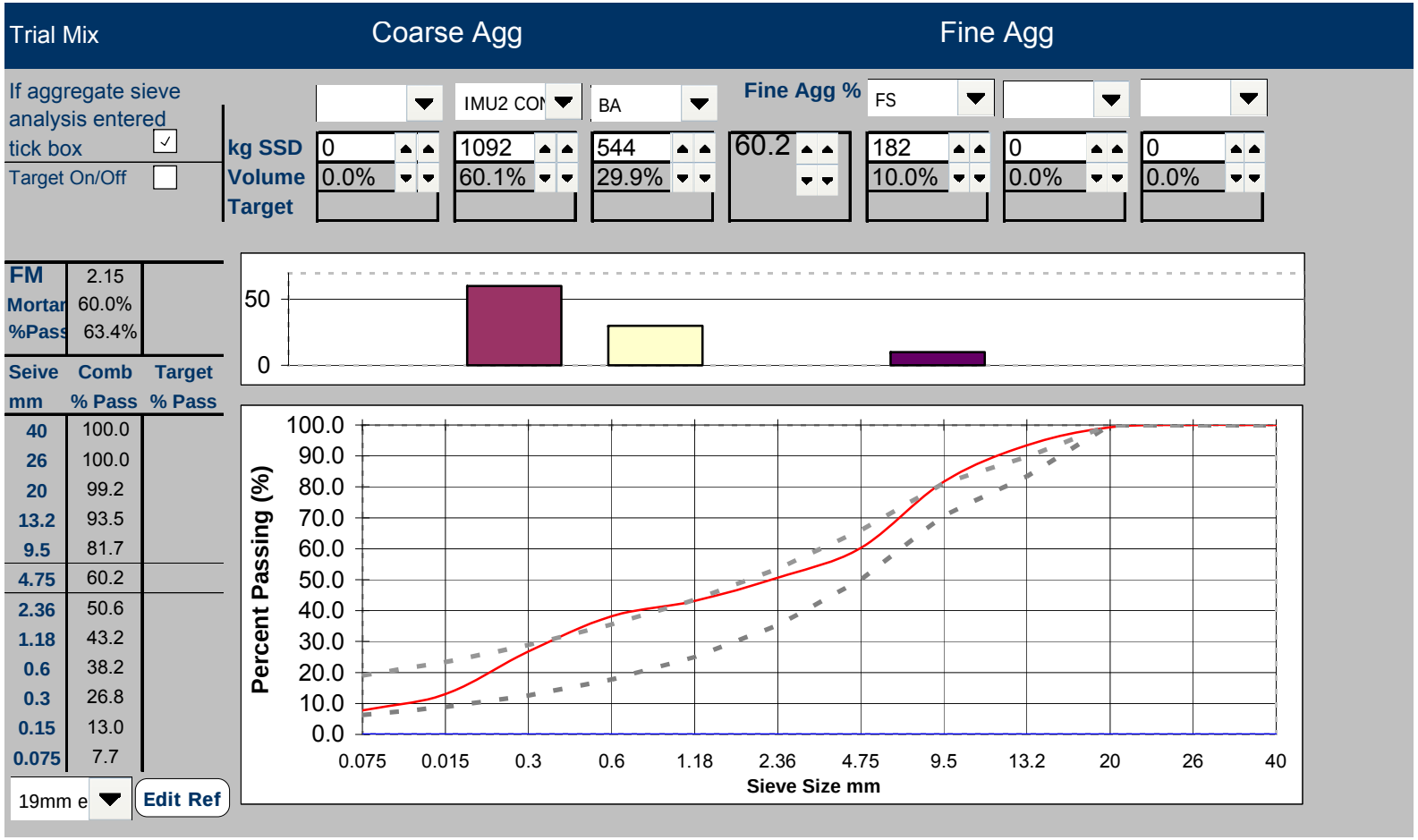
Blend 37


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1090
182
62.9
547
0
0
0.0%
60.0%
10.0%
30.0%
0.0%
0.0%
FM 2.06
Mortar 65.1%
%Pass 71.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.2
13.2 94.3
9.5 83.1
4.75 62.9
2.36 54.8
1.18 48.9
0.6 45.1
0.3 28.9
0.15 7.1
0.075 4.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

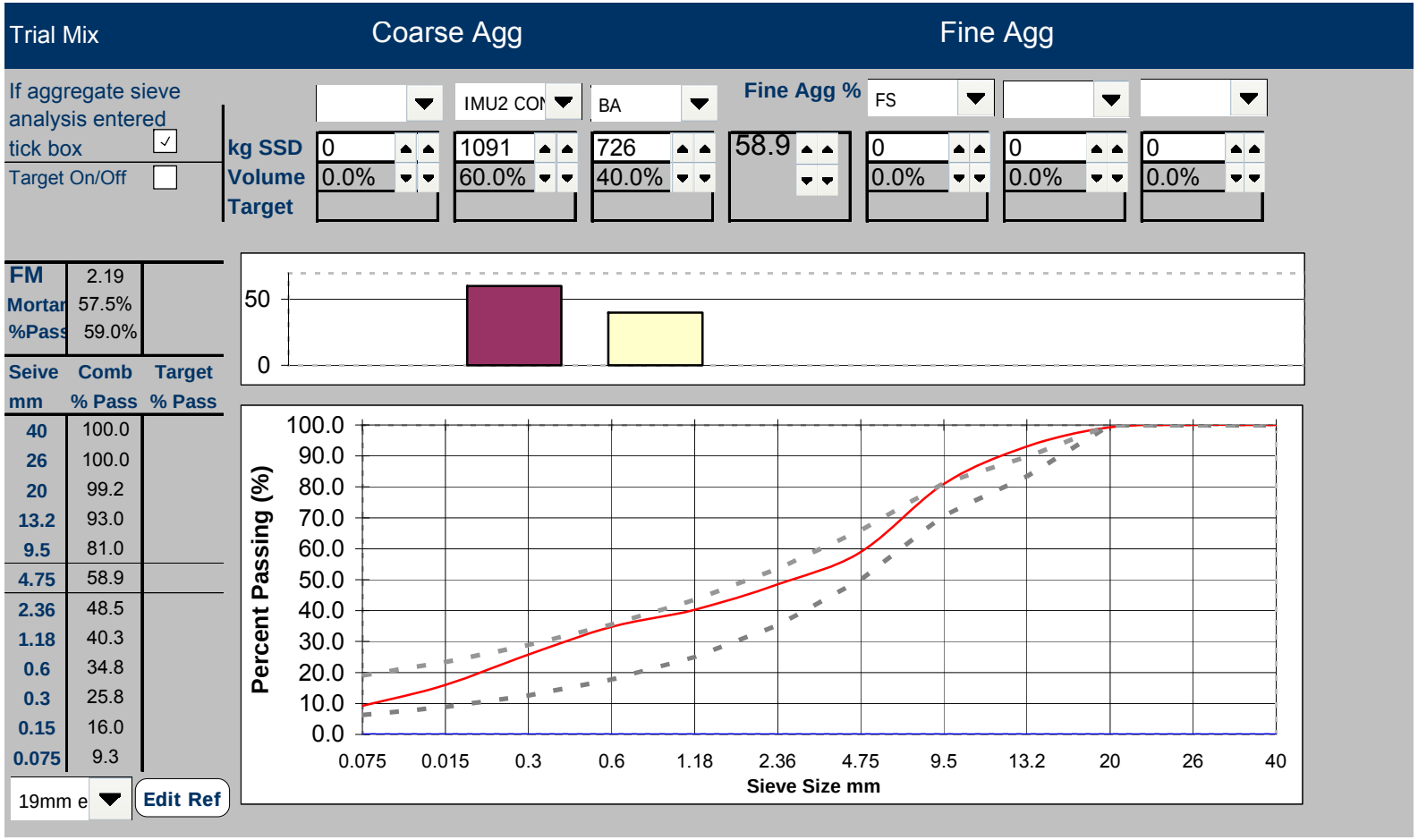
Blend 38


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1092
361
61.5
365
0
0
0.0%
60.1%
19.9%
20.0%
0.0%
0.0%
FM 2.11
Mortar 62.5%
%Pass 67.6%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.2
13.2 93.9
9.5 82.4
4.75 61.5
2.36 52.7
1.18 46.0
0.6 41.6
0.3 27.8
0.15 10.1
0.075 6.2
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

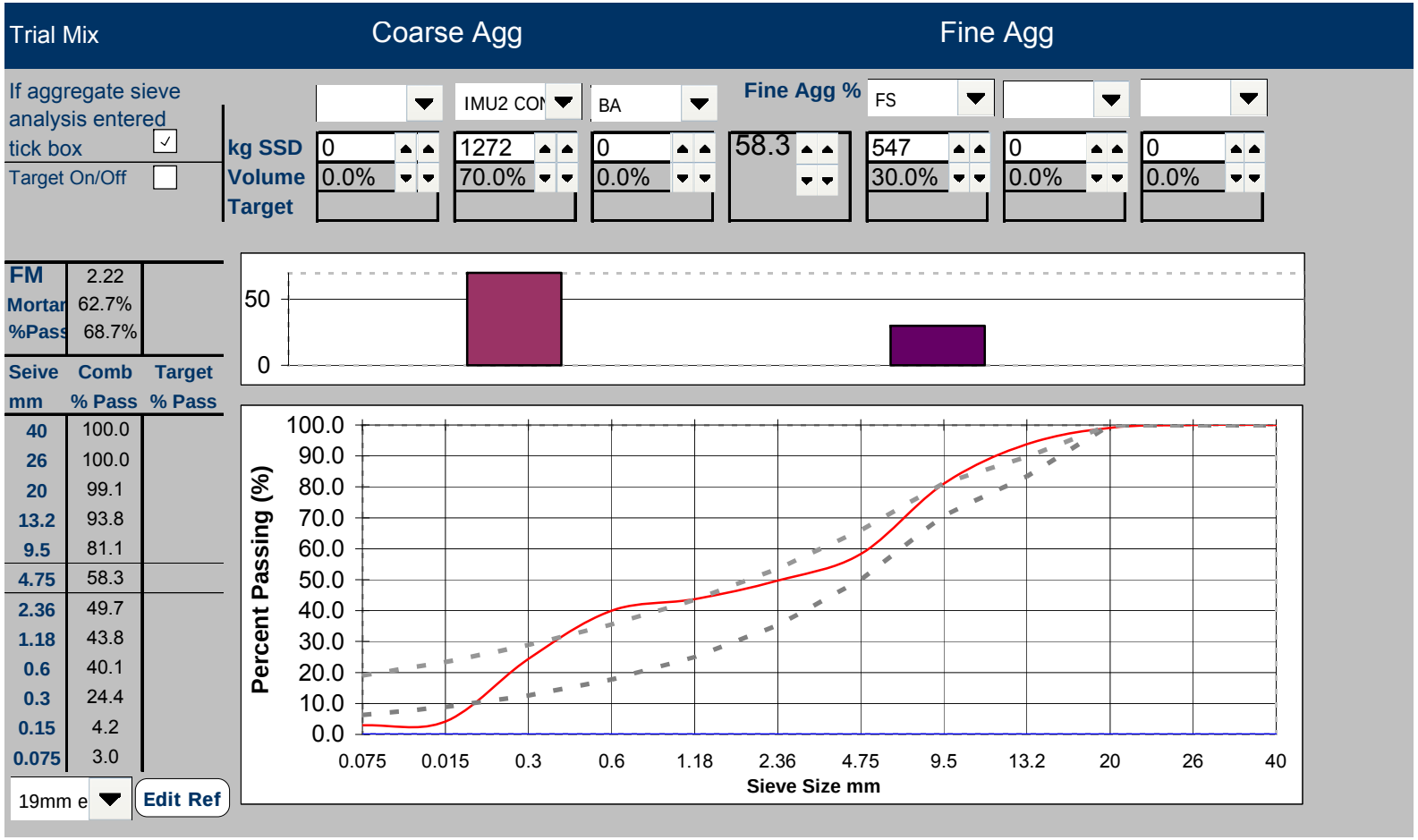
Blend 39


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1092
544
60.2
182
0
0
0.0%
60.1%
29.9%
10.0%
0.0%
0.0%
FM 2.15
Mortar 60.0%
%Pass 63.4%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.2
13.2 93.5
9.5 81.7
4.75 60.2
2.36 50.6
1.18 43.2
0.6 38.2
0.3 26.8
0.15 13.0
0.075 7.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

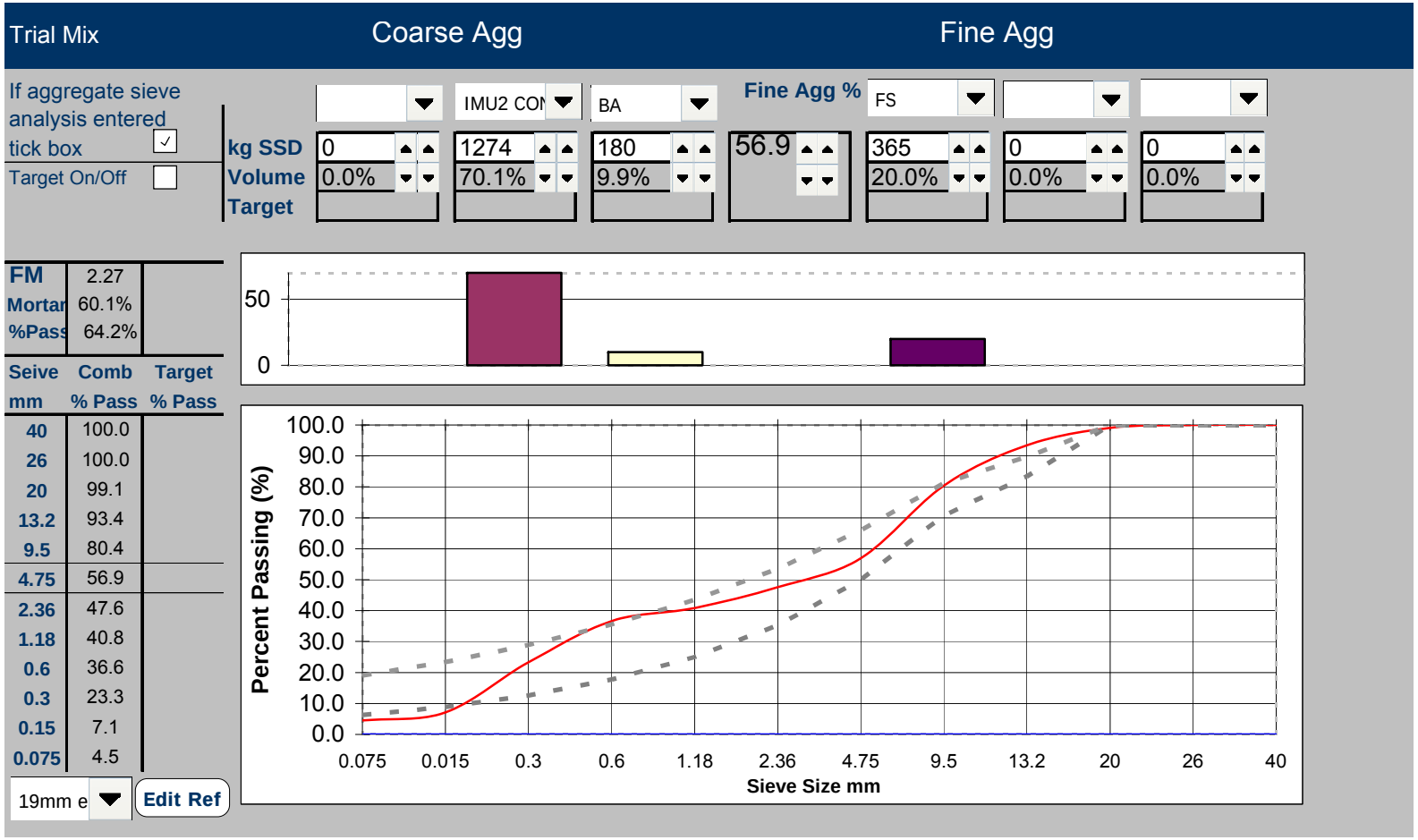
Blend 40


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1091
726
58.9
0
0
0
0.0%
60.0%
40.0%
0.0%
0.0%
0.0%
FM 2.19
Mortar 57.5%
%Pass 59.0%
50
0
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.2
13.2 93.0
9.5 81.0
4.75 58.9
2.36 48.5
1.18 40.3
0.6 34.8
0.3 25.8
0.15 16.0
0.075 9.3
19mm e
Edit Ref
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

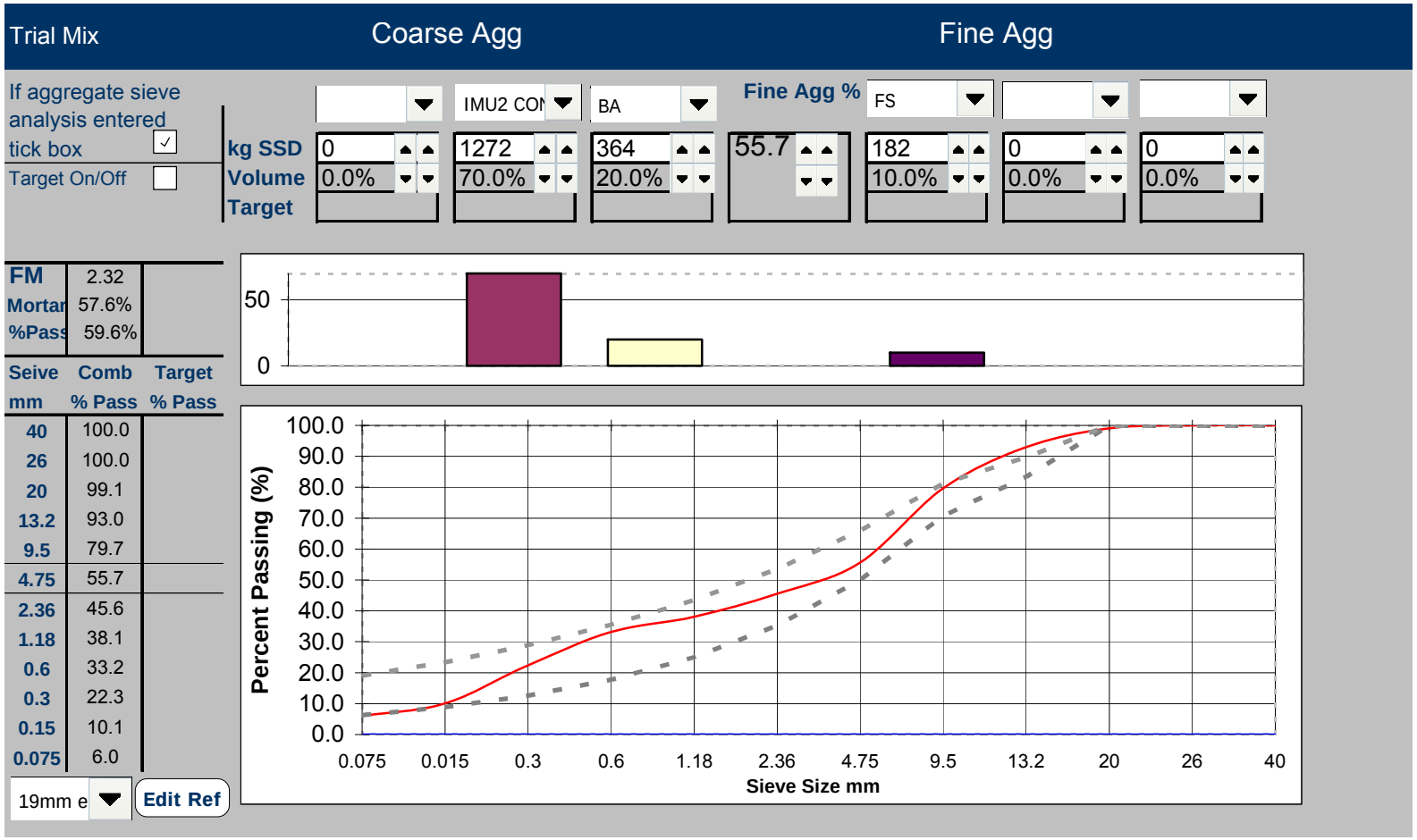
Blend 41


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1272
0
58.3
547
0
0
0.0%
70.0%
0.0%
30.0%
0.0%
0.0%
FM 2.22
Mortar 62.7%
%Pass 68.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.1
13.2 93.8
9.5 81.1
4.75 58.3
2.36 49.7
1.18 43.8
0.6 40.1
0.3 24.4
0.15 4.2
0.075 3.0
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

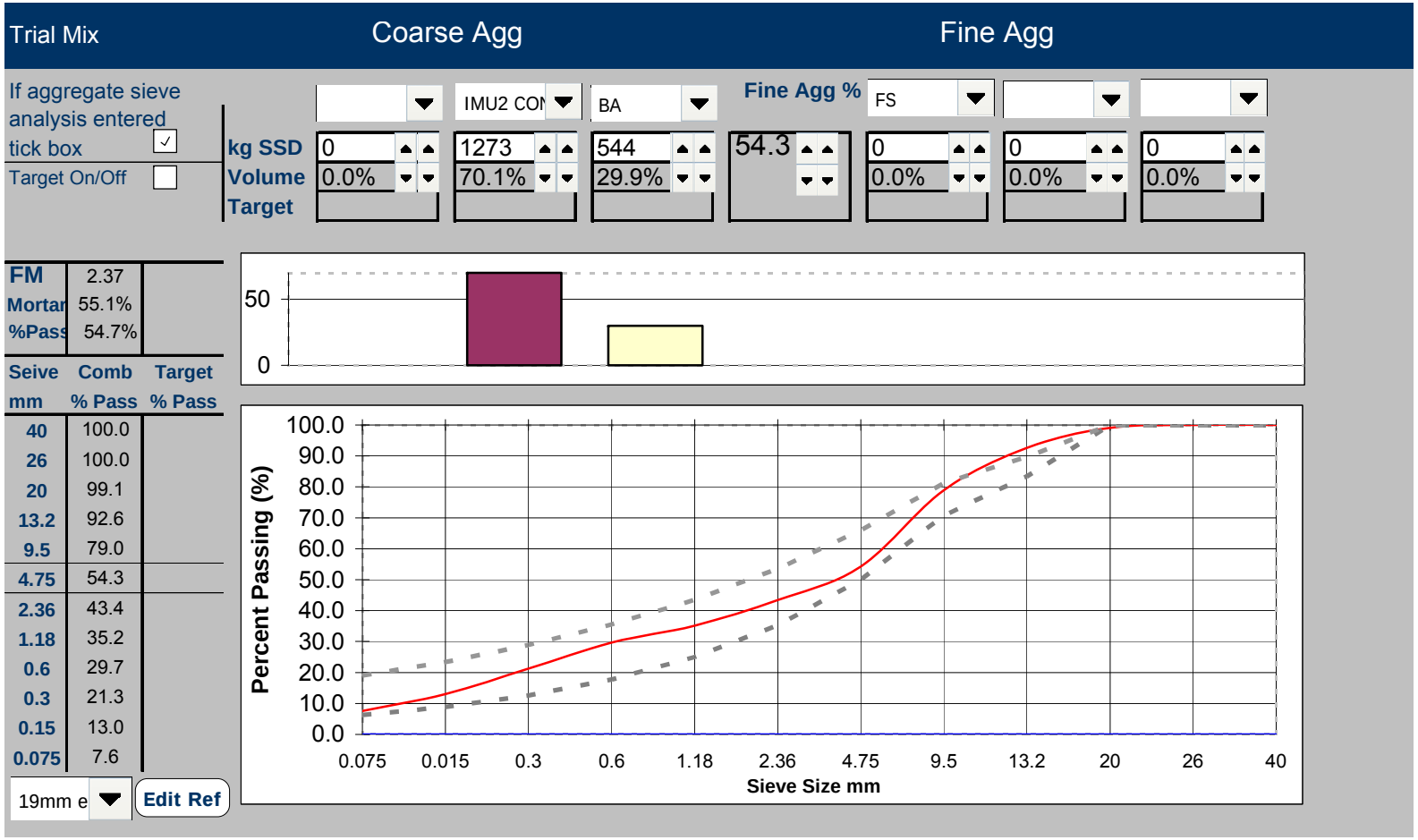
Blend 42


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1274
180
56.9
365
0
0
0.0%
70.1%
9.9%
20.0%
0.0%
0.0%
FM 2.27
Mortar 60.1%
%Pass 64.2%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.1
13.2 93.4
9.5 80.4
4.75 56.9
2.36 47.6
1.18 40.8
0.6 36.6
0.3 23.3
0.15 7.1
0.075 4.5
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

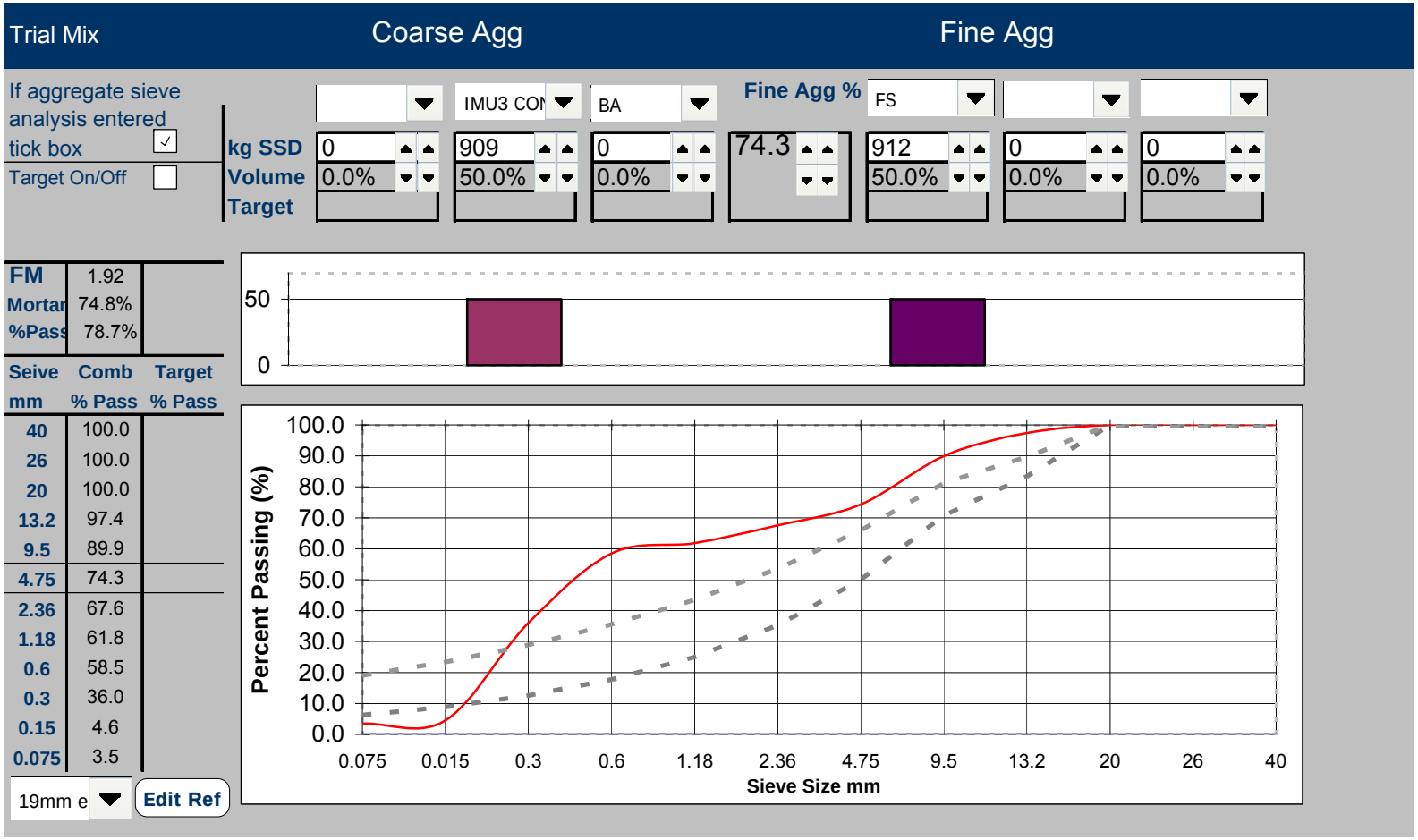
Blend 43


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1272
364
55.7
182
0
0
0.0%
70.0%
20.0%
10.0%
0.0%
0.0%
FM 2.32
Mortar 57.6%
%Pass 59.6%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.1
13.2 93.0
9.5 79.7
4.75 55.7
2.36 45.6
1.18 38.1
0.6 33.2
0.3 22.3
0.15 10.1
0.075 6.0
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

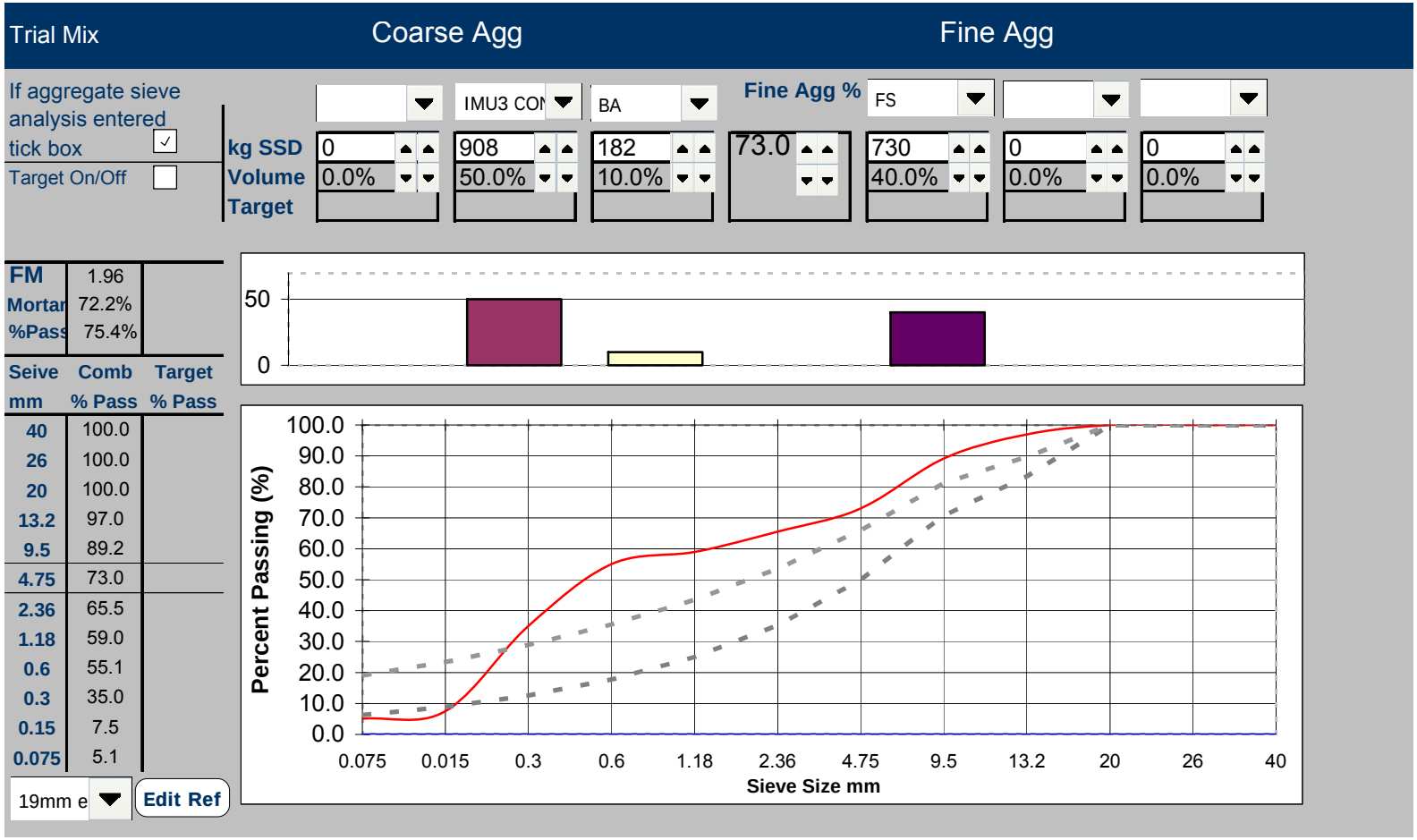
Blend 44


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU2 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1273
544
54.3
0
0
0
0.0%
70.1%
29.9%
0.0%
0.0%
0.0%
FM 2.37
Mortar 55.1%
%Pass 54.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 99.1
13.2 92.6
9.5 79.0
4.75 54.3
2.36 43.4
1.18 35.2
0.6 29.7
0.3 21.3
0.15 13.0
0.075 7.6
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

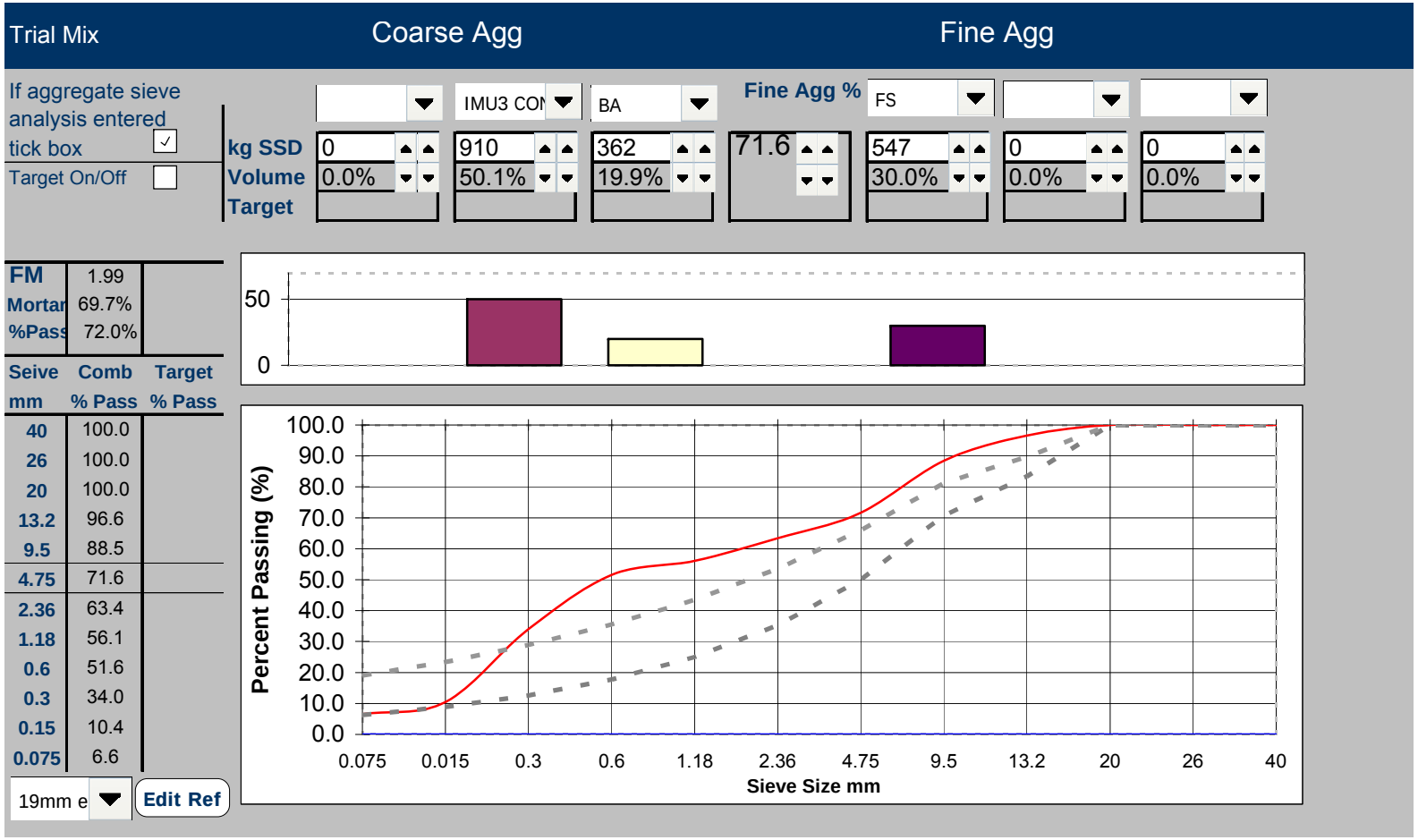
Blend 45


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
909
0
74.3
912
0
0
0.0%
50.0%
0.0%
50.0%
0.0%
0.0%
FM 1.92
Mortar 74.8%
%Pass 78.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 97.4
9.5 89.9
4.75 74.3
2.36 67.6
1.18 61.8
0.6 58.5
0.3 36.0
0.15 4.6
0.075 3.5
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

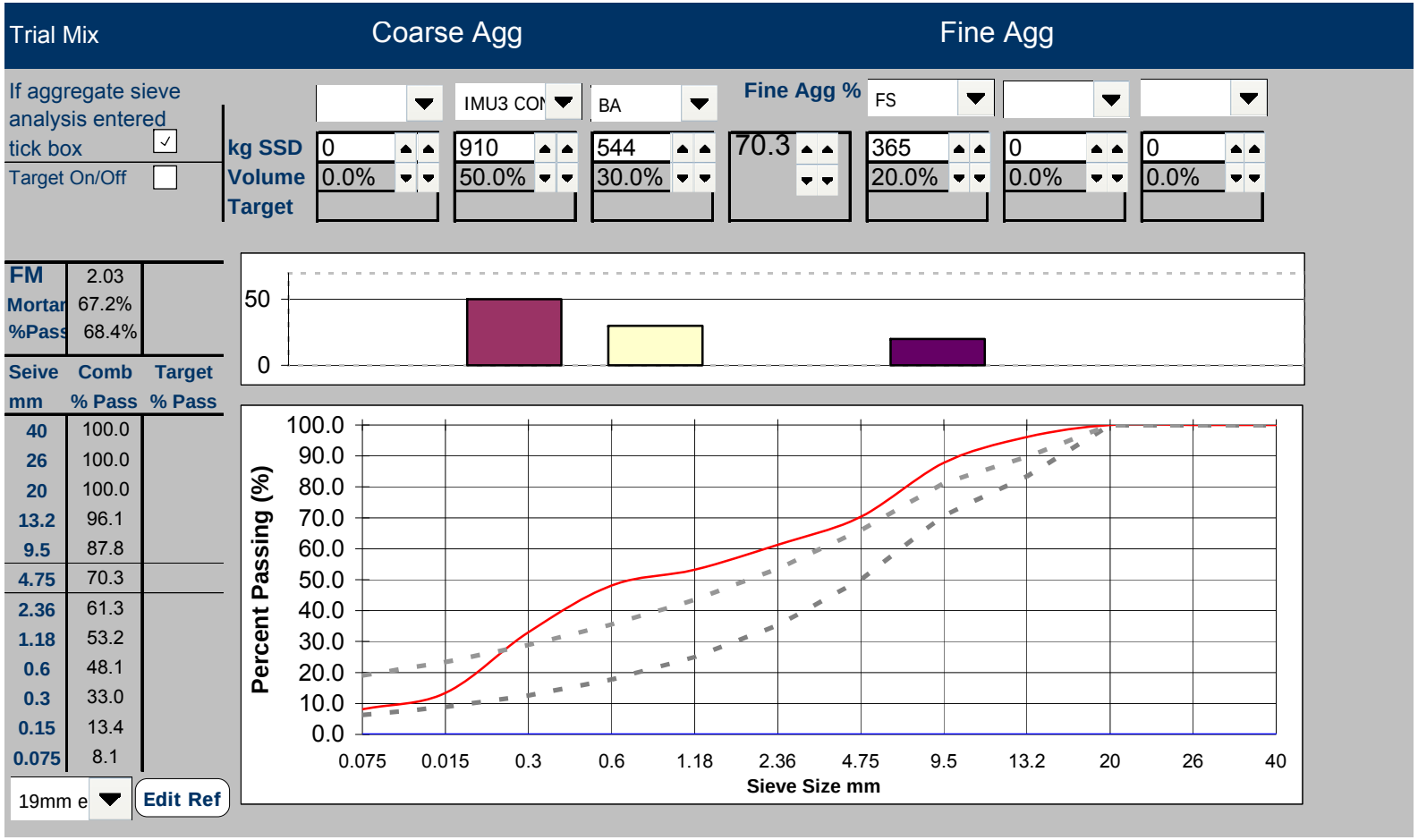
Blend 46


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
908
182
73.0
730
0
0
0.0%
50.0%
10.0%
40.0%
0.0%
0.0%
FM 1.96
Mortar 72.2%
%Pass 75.4%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 97.0
9.5 89.2
4.75 73.0
2.36 65.5
1.18 59.0
0.6 55.1
0.3 35.0
0.15 7.5
0.075 5.1
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

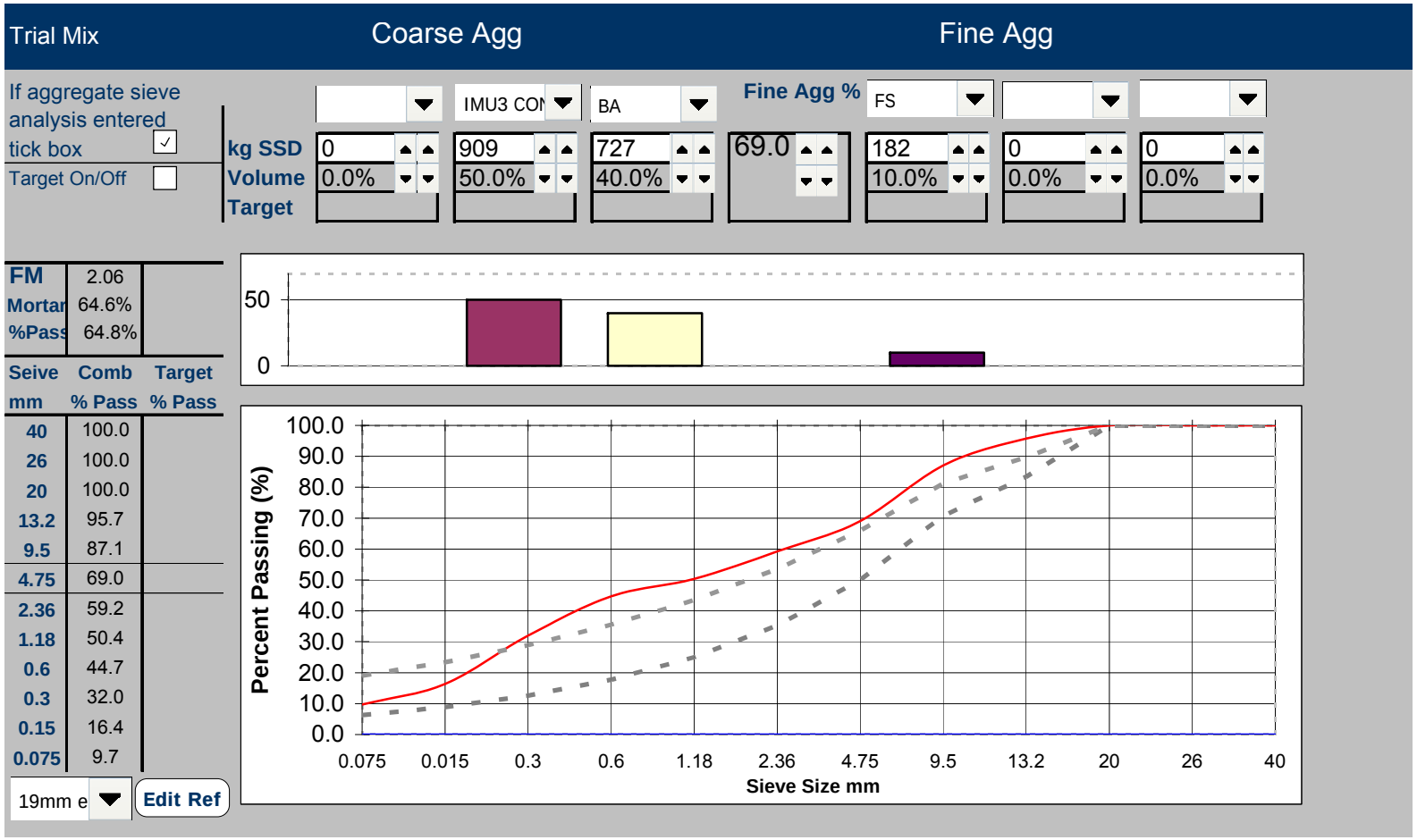
Blend 47


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
910
362
71.6
547
0
0
0.0%
50.1%
19.9%
30.0%
0.0%
0.0%
FM 1.99
Mortar 69.7%
%Pass 72.0%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.6
9.5 88.5
4.75 71.6
2.36 63.4
1.18 56.1
0.6 51.6
0.3 34.0
0.15 10.4
0.075 6.6
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

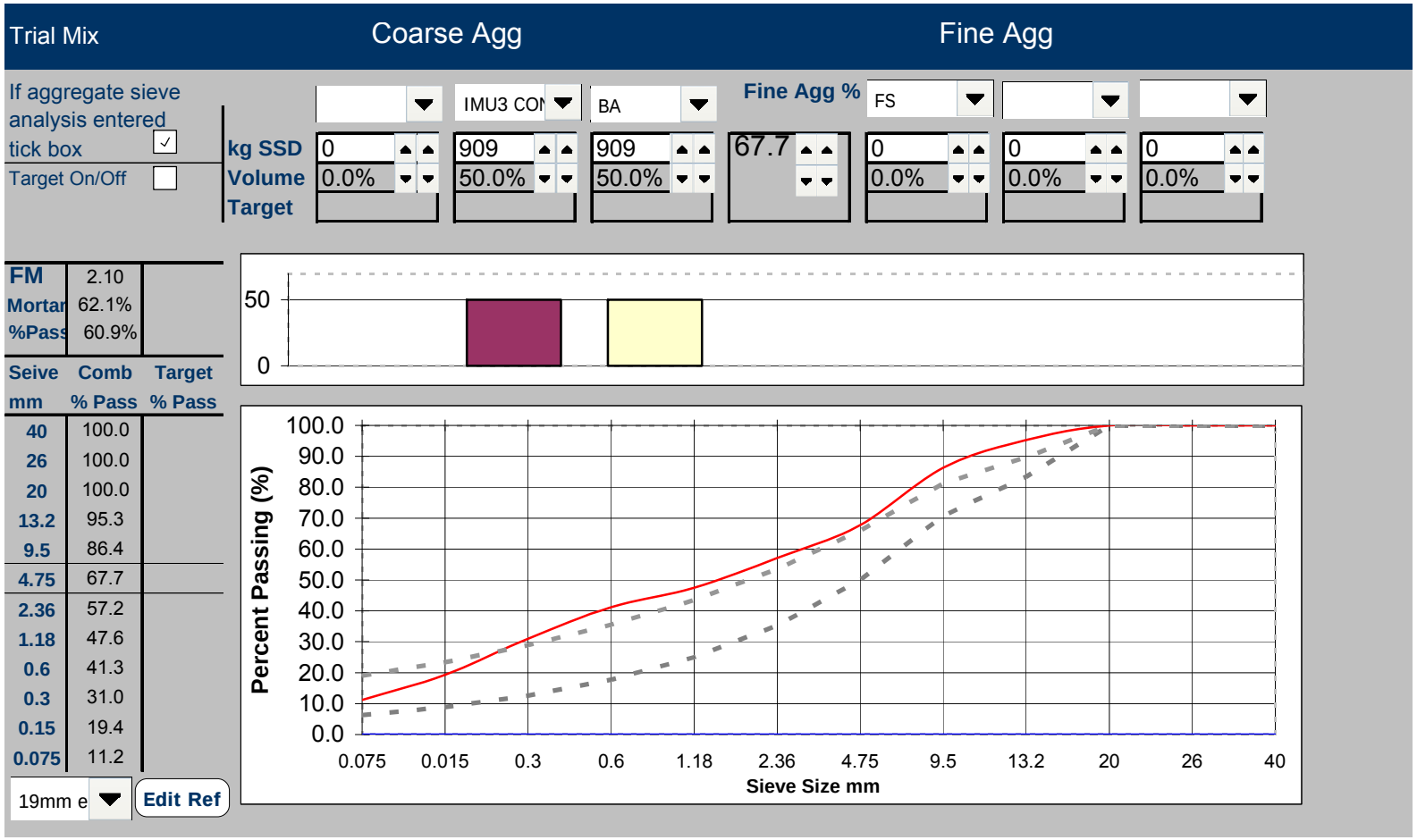
Blend 48


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
910
544
70.3
365
0
0
0.0%
50.0%
30.0%
20.0%
0.0%
0.0%
FM 2.03
Mortar 67.2%
%Pass 68.4%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.1
9.5 87.8
4.75 70.3
2.36 61.3
1.18 53.2
0.6 48.1
0.3 33.0
0.15 13.4
0.075 8.1
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

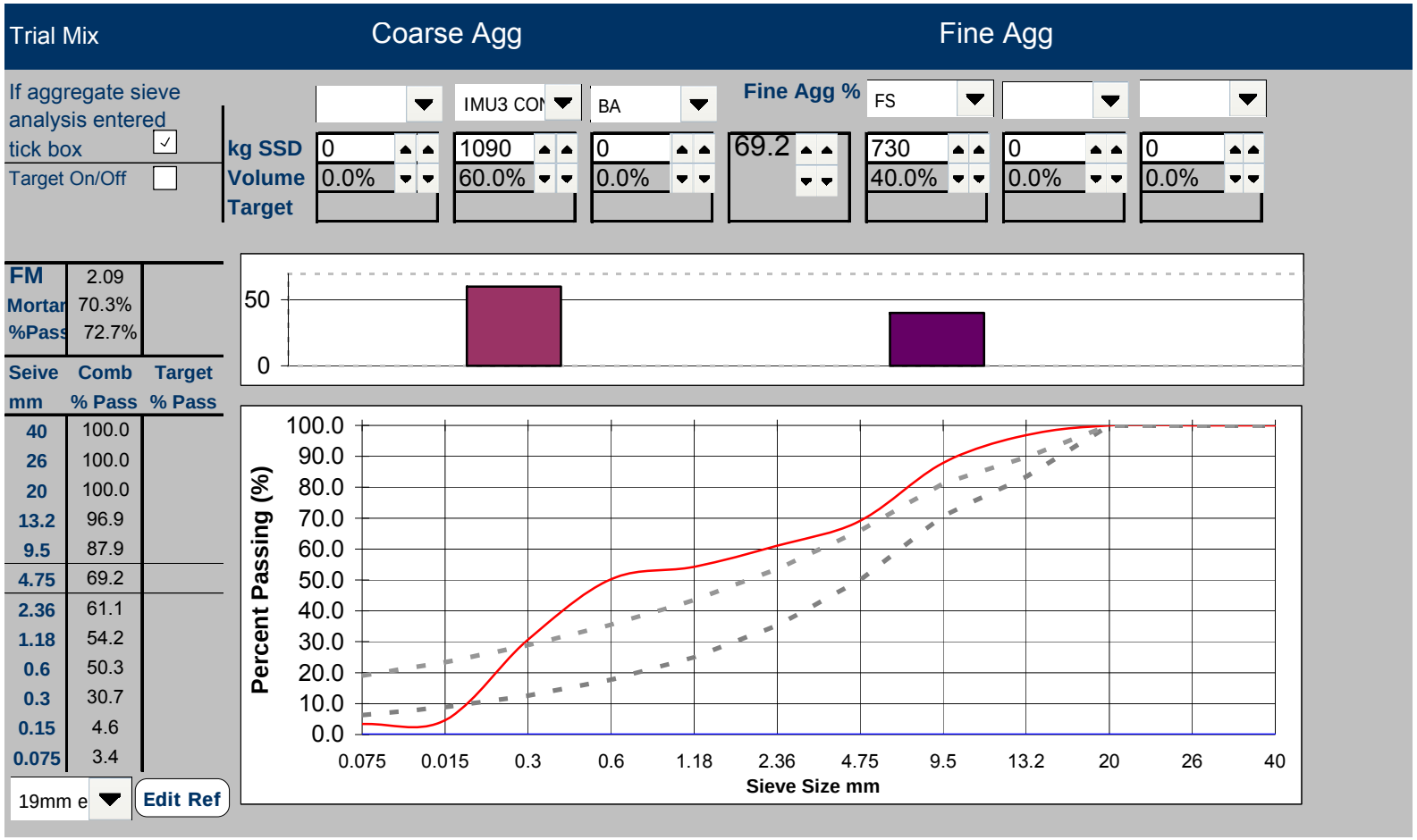
Blend 49


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
909
727
69.0
182
0
0
0.0%
50.0%
40.0%
10.0%
0.0%
0.0%
FM 2.06
Mortar 64.6%
%Pass 64.8%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 95.7
9.5 87.1
4.75 69.0
2.36 59.2
1.18 50.4
0.6 44.7
0.3 32.0
0.15 16.4
0.075 9.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

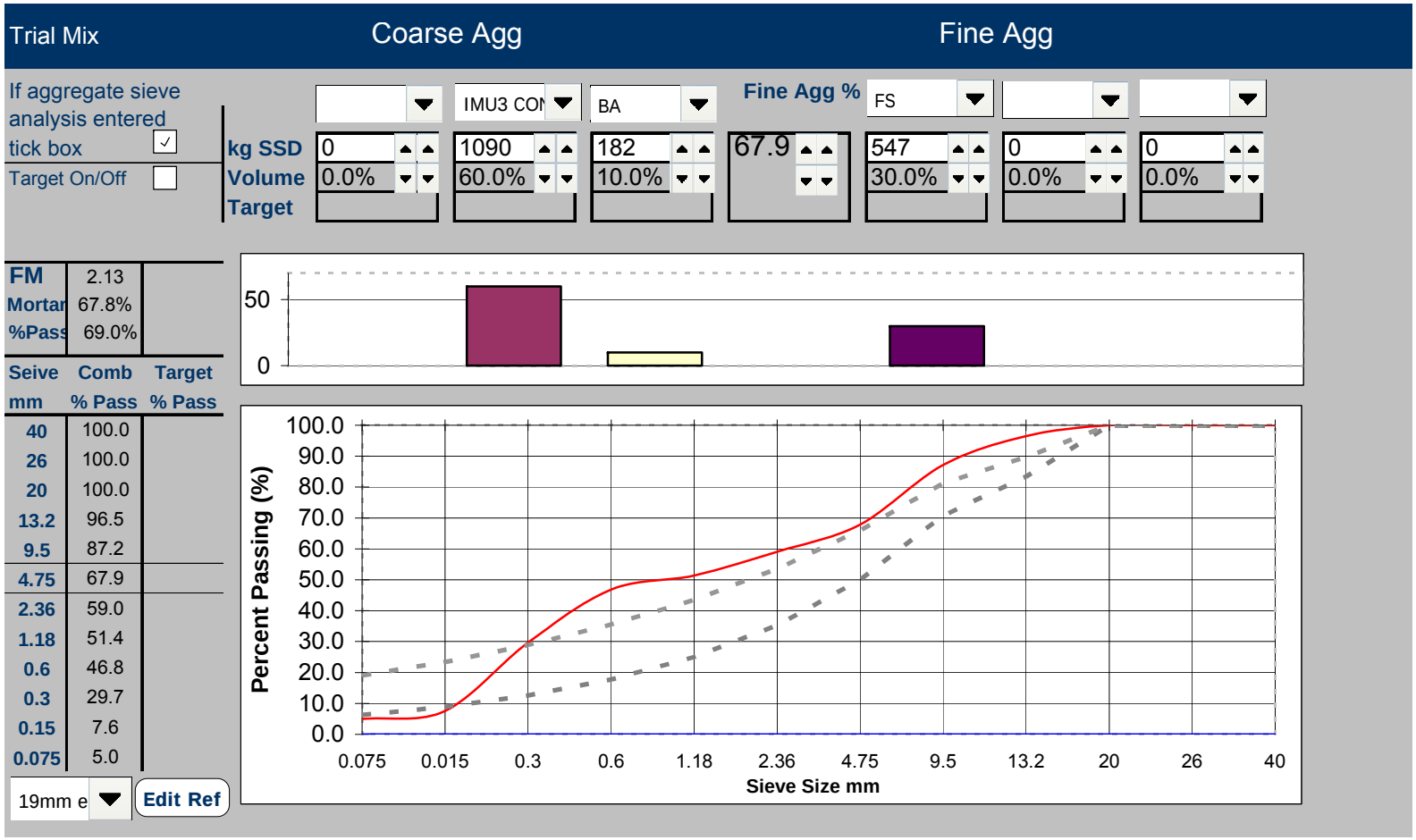
Blend 50


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
909
909
67.7
0
0
0
0.0%
50.0%
50.0%
0.0%
0.0%
0.0%
FM 2.10
Mortar 62.1%
%Pass 60.9%
50
0
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 95.3
9.5 86.4
4.75 67.7
2.36 57.2
1.18 47.6
0.6 41.3
0.3 31.0
0.15 19.4
0.075 11.2
19mm e
Edit Ref
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

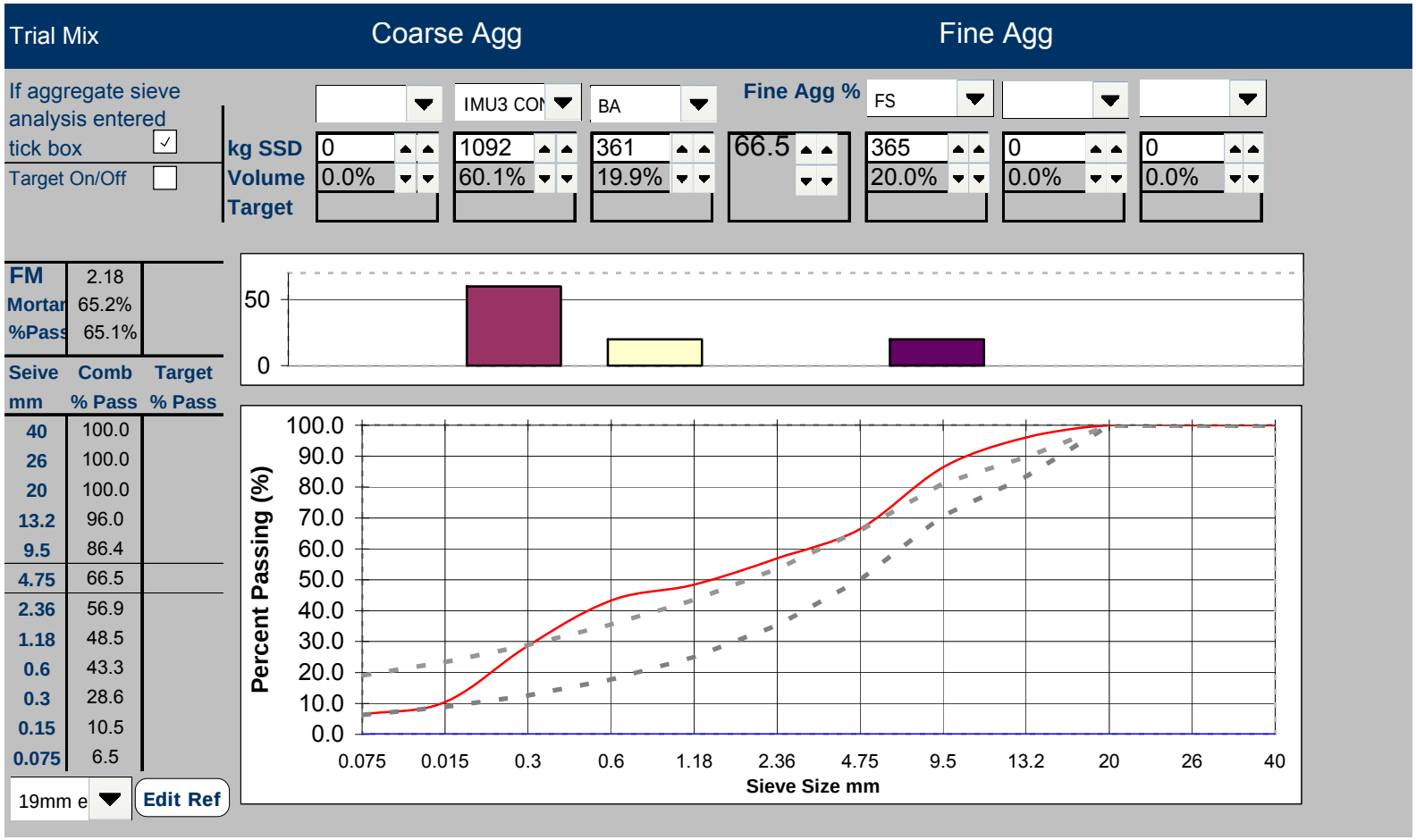
Blend 51


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1090
0
69.2
730
0
0
0.0%
60.0%
0.0%
40.0%
0.0%
0.0%
FM 2.09
Mortar 70.3%
%Pass 72.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.9
9.5 87.9
4.75 69.2
2.36 61.1
1.18 54.2
0.6 50.3
0.3 30.7
0.15 4.6
0.075 3.4
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

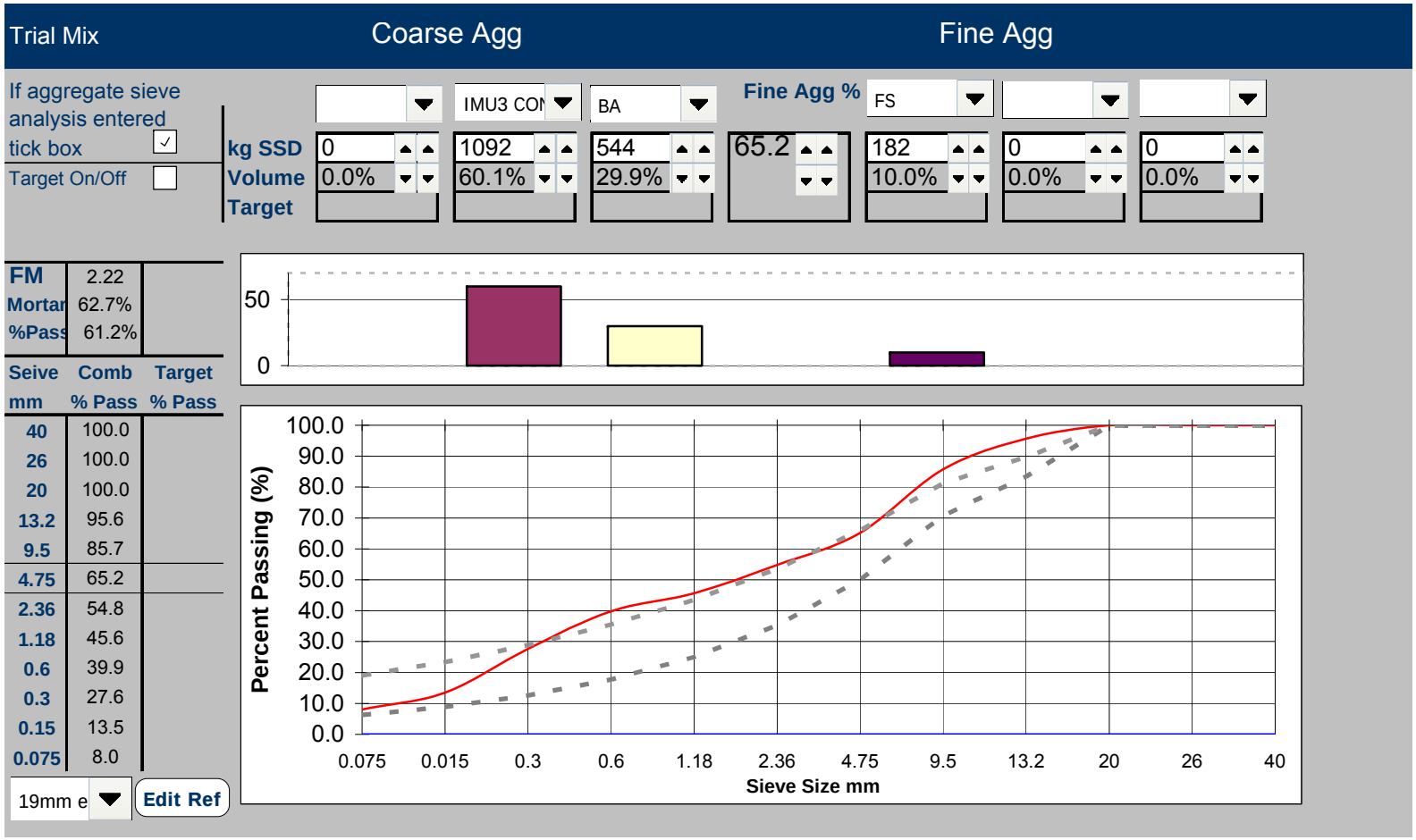
Blend 52


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
kg SSD
Volume
Target
IMU3 CON
BA
Fine Agg %
FS
0
1090
182
67.9
547
0
0
0.0%
60.0%
10.0%
30.0%
0.0%
0.0%
FM 2.13
Mortar 67.8%
%Pass 69.0%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.5
9.5 87.2
4.75 67.9
2.36 59.0
1.18 51.4
0.6 46.8
0.3 29.7
0.15 7.6
0.075 5.0
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

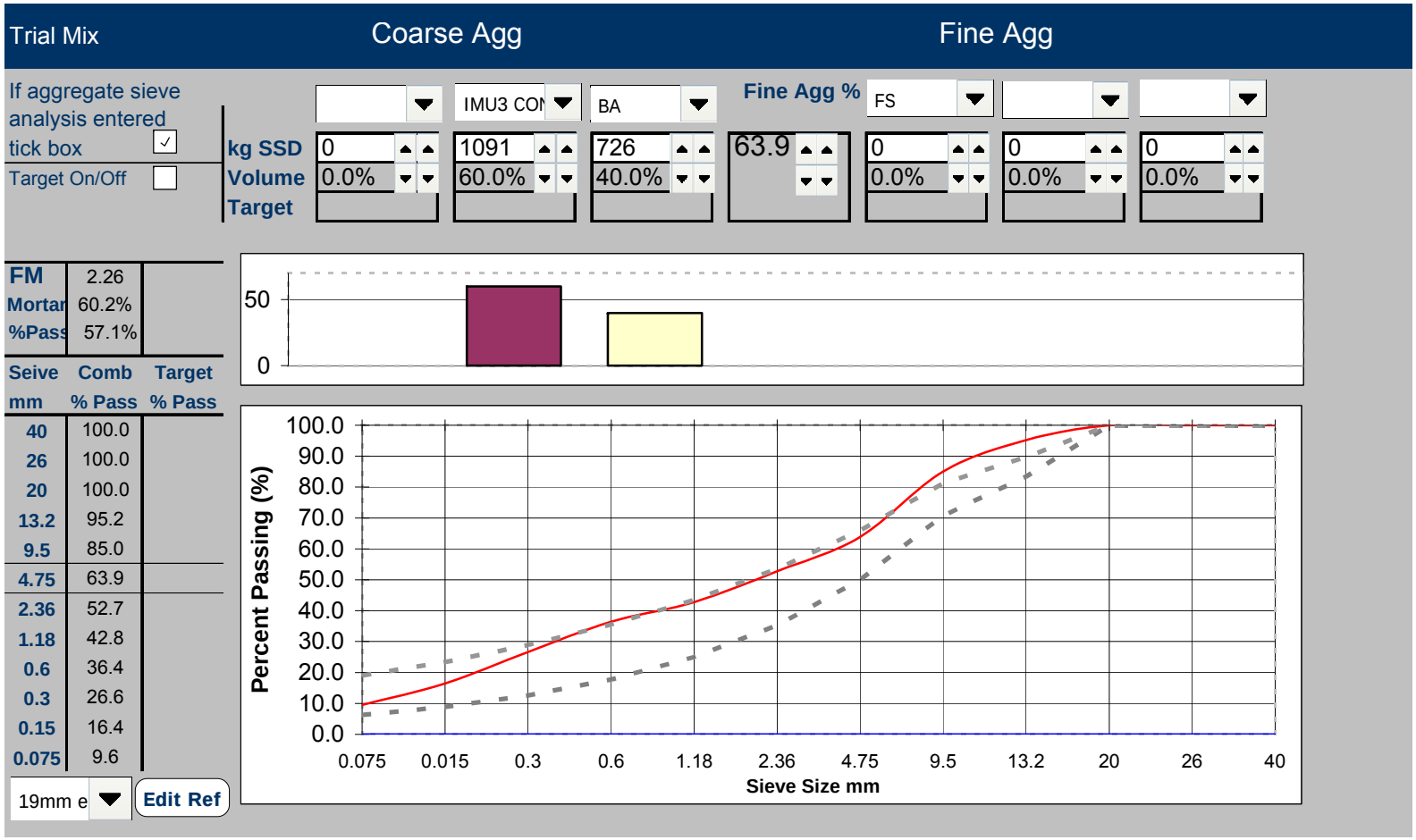
Blend 53


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
kg SSD
Volume
Target
IMU3 CON
BA
Fine Agg %
FS
0
1092
361
66.5
365
0
0
0.0%
60.1%
19.9%
20.0%
0.0%
0.0%
FM 2.18
Mortar 65.2%
%Pass 65.1%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.0
9.5 86.4
4.75 66.5
2.36 56.9
1.18 48.5
0.6 43.3
0.3 28.6
0.15 10.5
0.075 6.5
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

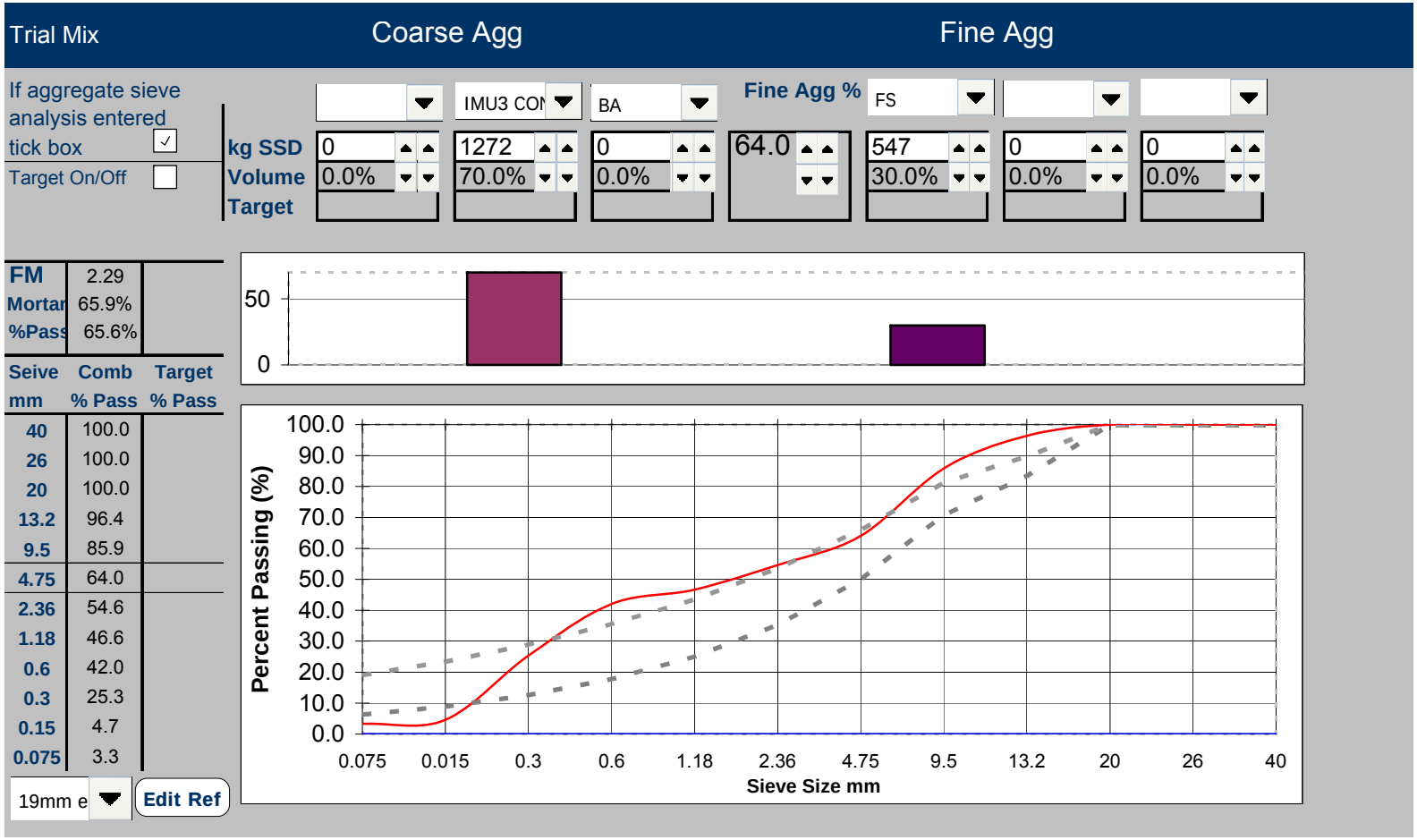
Blend 54


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
kg SSD
Volume
Target
IMU3 CON
BA
Fine Agg %
FS
0
1092
544
65.2
182
0
0
0.0%
60.1%
29.9%
10.0%
0.0%
0.0%
FM 2.22
Mortar 62.7%
%Pass 61.2%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 95.6
9.5 85.7
4.75 65.2
2.36 54.8
1.18 45.6
0.6 39.9
0.3 27.6
0.15 13.5
0.075 8.0
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

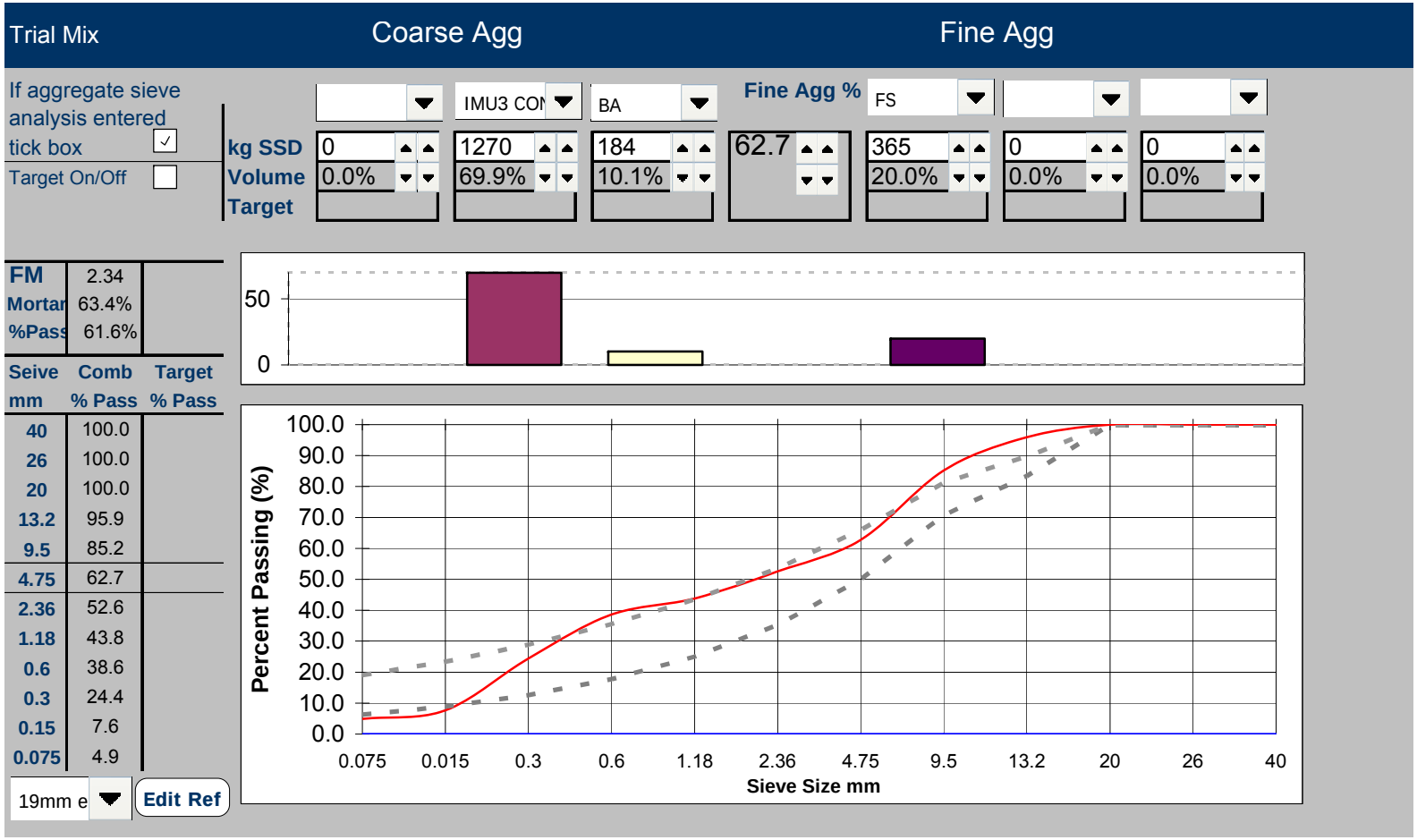
Blend 55


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1091
726
63.9
0
0
0
0.0%
60.0%
40.0%
0.0%
0.0%
0.0%
FM 2.26
Mortar 60.2%
%Pass 57.1%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 95.2
9.5 85.0
4.75 63.9
2.36 52.7
1.18 42.8
0.6 36.4
0.3 26.6
0.15 16.4
0.075 9.6
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

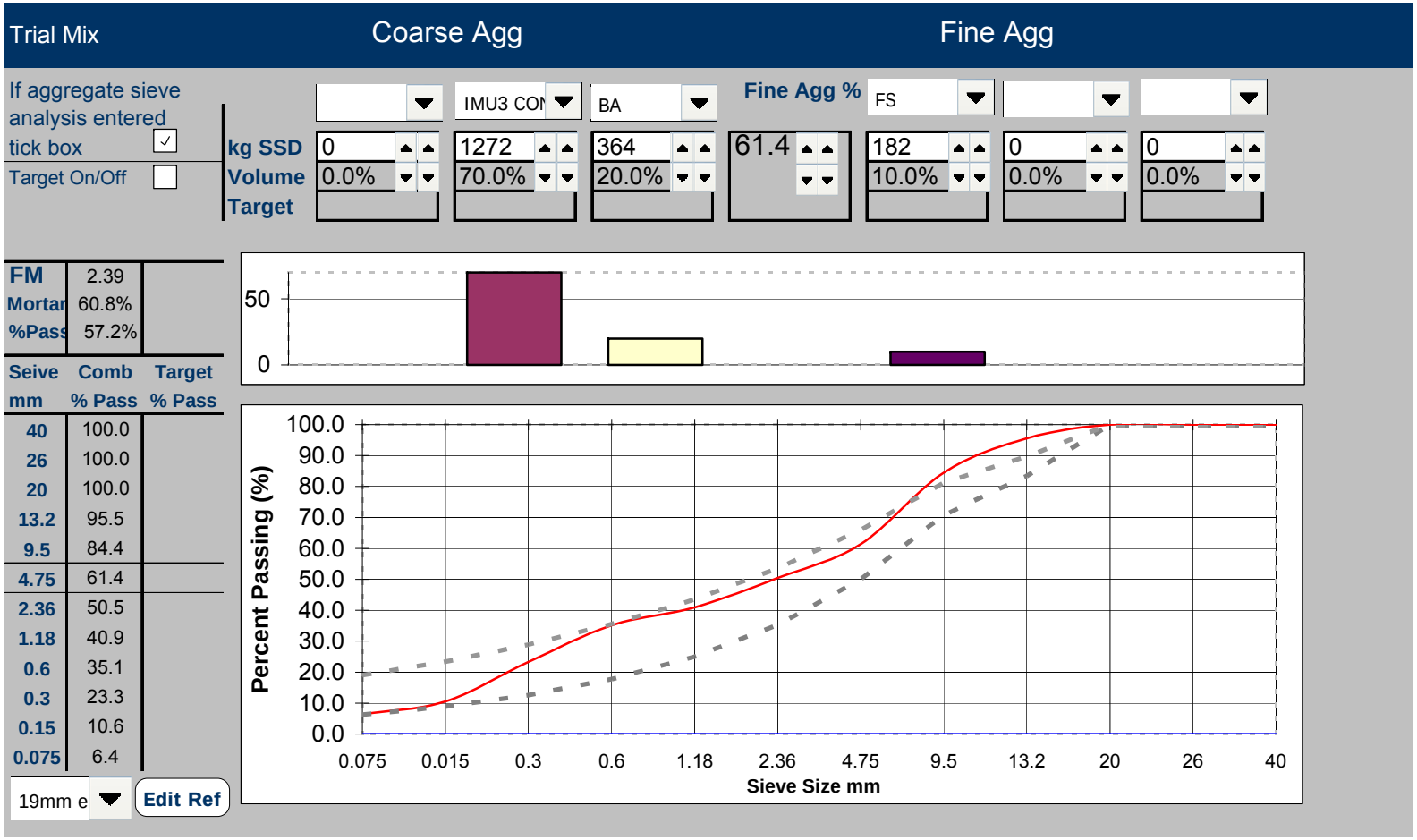
Blend 56


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1272
0
64.0
547
0
0
0.0%
70.0%
0.0%
30.0%
0.0%
0.0%
FM 2.29
Mortar 65.9%
%Pass 65.6%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.4
9.5 85.9
4.75 64.0
2.36 54.6
1.18 46.6
0.6 42.0
0.3 25.3
0.15 4.7
0.075 3.3
19mm e
Edit Ref
50
0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Percent Passing (%)
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

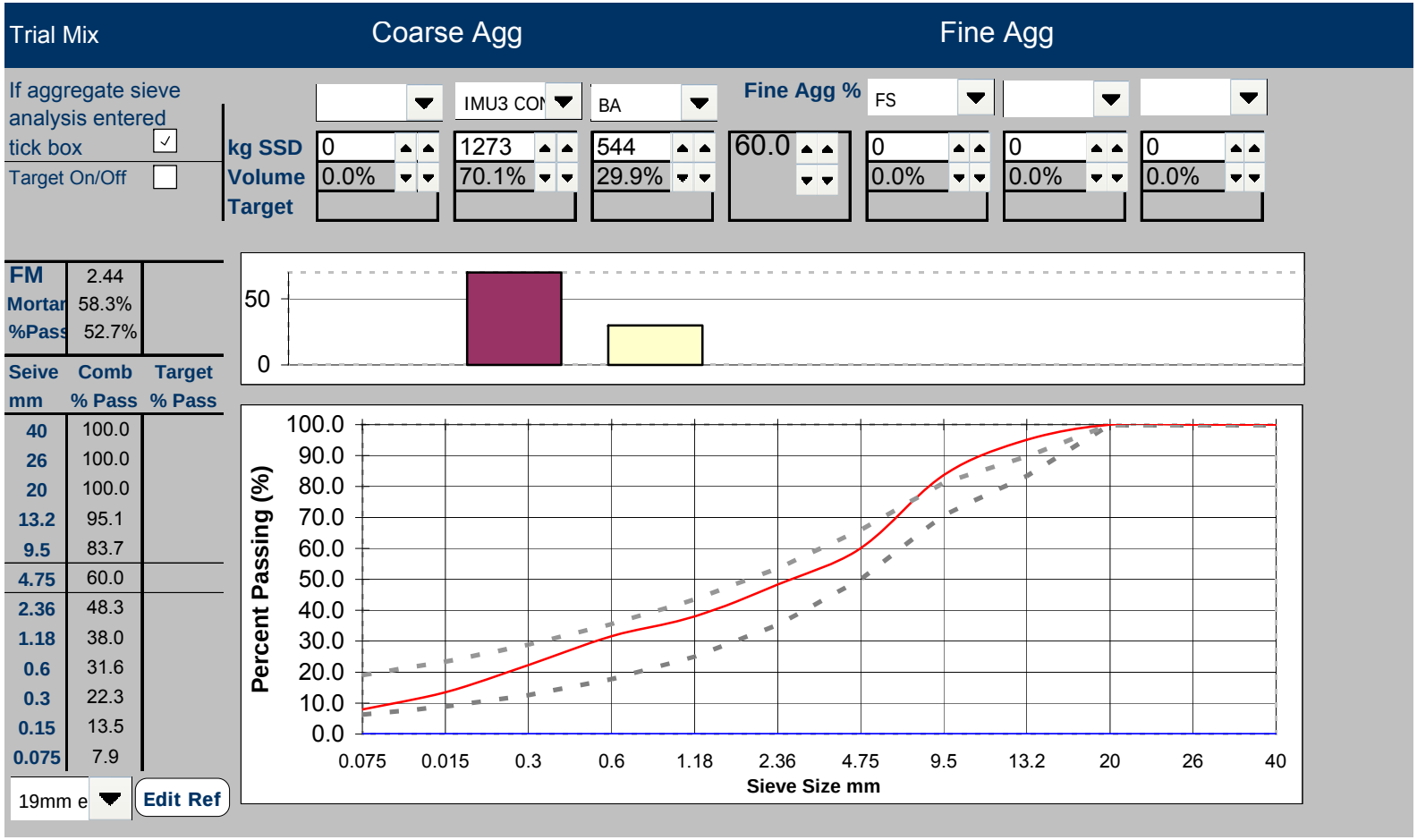
Blend 57


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1270
184
62.7
365
0
0
0.0%
69.9%
10.1%
20.0%
0.0%
0.0%
FM 2.34
Mortar 63.4%
%Pass 61.6%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 95.9
9.5 85.2
4.75 62.7
2.36 52.6
1.18 43.8
0.6 38.6
0.3 24.4
0.15 7.6
0.075 4.9
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

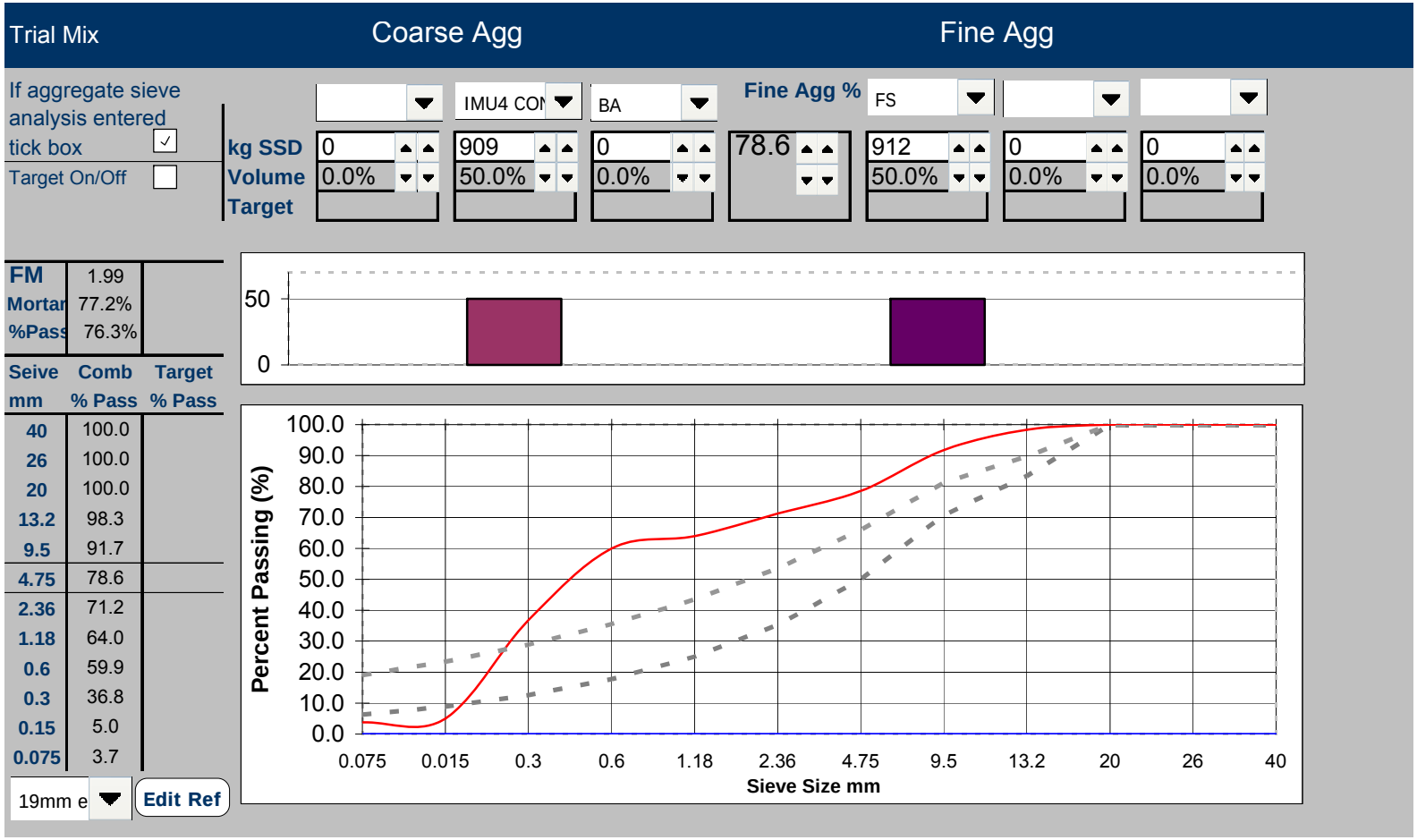
Blend 58


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU3 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1272
364
61.4
182
0
0
0.0%
70.0%
20.0%
10.0%
0.0%
0.0%
FM 2.39
Mortar 60.8%
%Pass 57.2%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 95.5
9.5 84.4
4.75 61.4
2.36 50.5
1.18 40.9
0.6 35.1
0.3 23.3
0.15 10.6
0.075 6.4
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

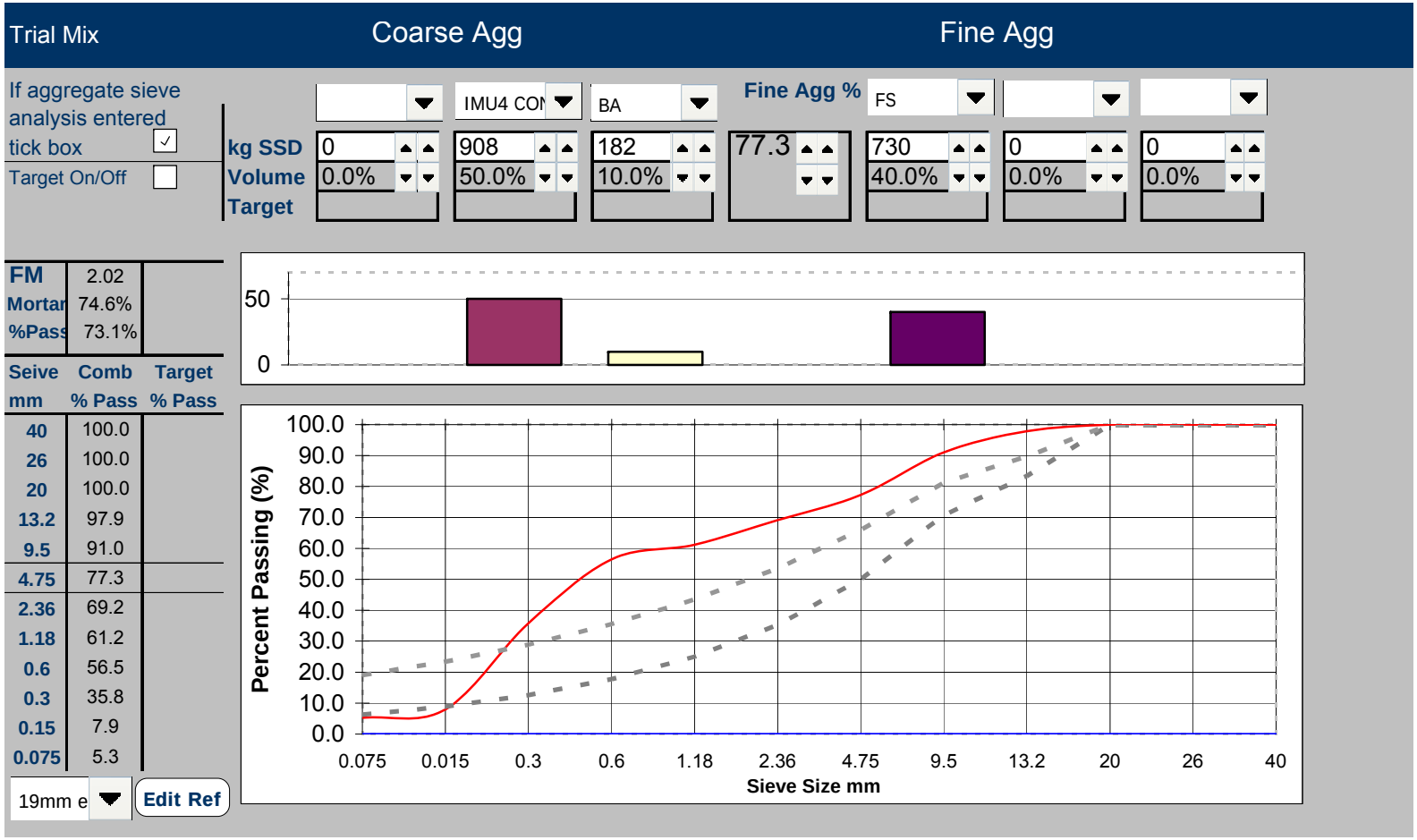
Blend 59


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
kg SSD
Volume
Target
IMU3 CON
BA
Fine Agg %
FS
0
1273
544
60.0
0
0
0
0.0%
70.1%
29.9%
0.0%
0.0%
0.0%
FM 2.44
Mortar 58.3%
%Pass 52.7%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 95.1
9.5 83.7
4.75 60.0
2.36 48.3
1.18 38.0
0.6 31.6
0.3 22.3
0.15 13.5
0.075 7.9
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

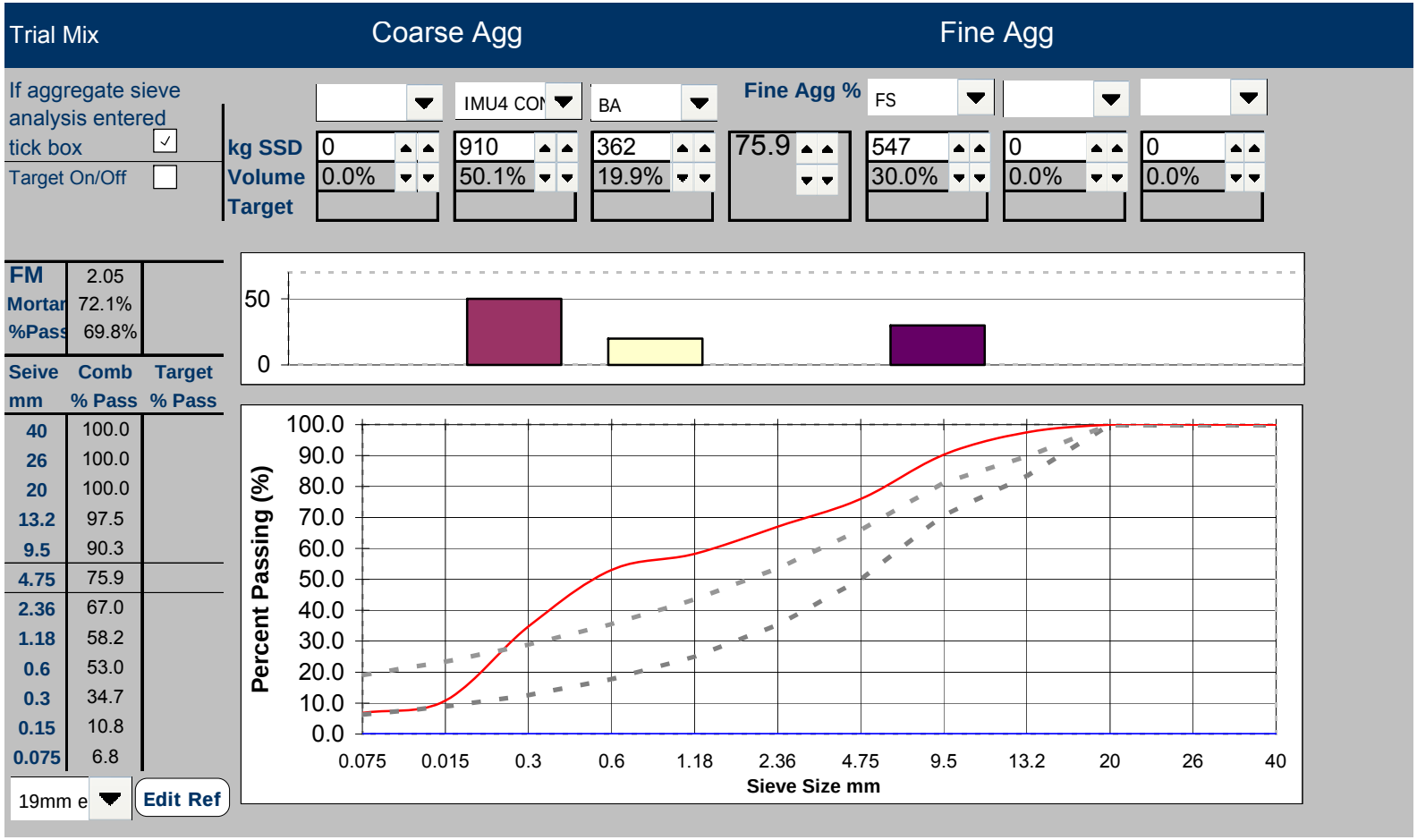
Blend 60


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
909
0
78.6
912
0
0
0.0%
50.0%
0.0%
50.0%
0.0%
0.0%
FM 1.99
Mortar 77.2%
%Pass 76.3%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 98.3
9.5 91.7
4.75 78.6
2.36 71.2
1.18 64.0
0.6 59.9
0.3 36.8
0.15 5.0
0.075 3.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

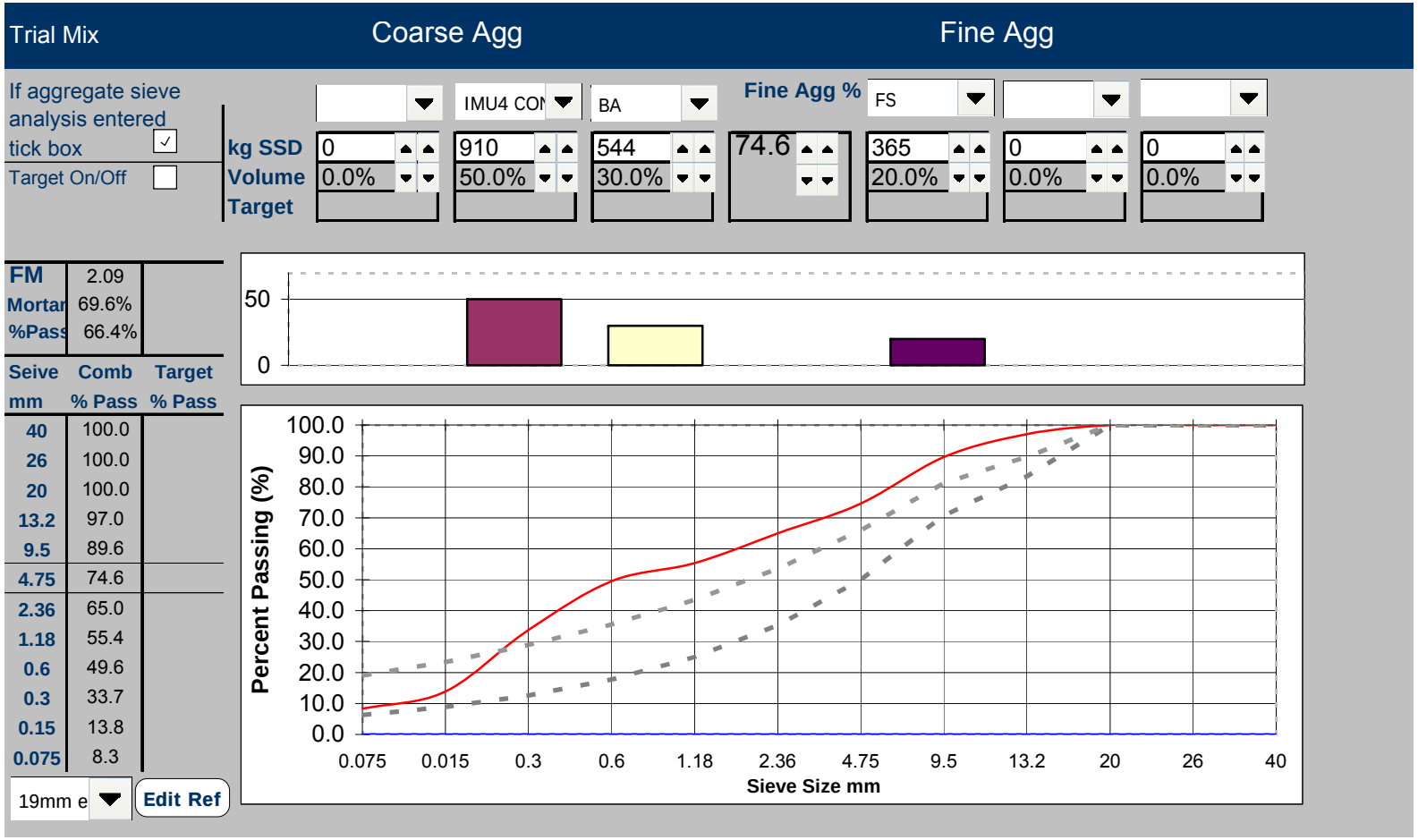
Blend 61


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
908
182
77.3
730
0
0
0.0%
50.0%
10.0%
40.0%
0.0%
0.0%
FM 2.02
Mortar 74.6%
%Pass 73.1%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 97.9
9.5 91.0
4.75 77.3
2.36 69.2
1.18 61.2
0.6 56.5
0.3 35.8
0.15 7.9
0.075 5.3
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

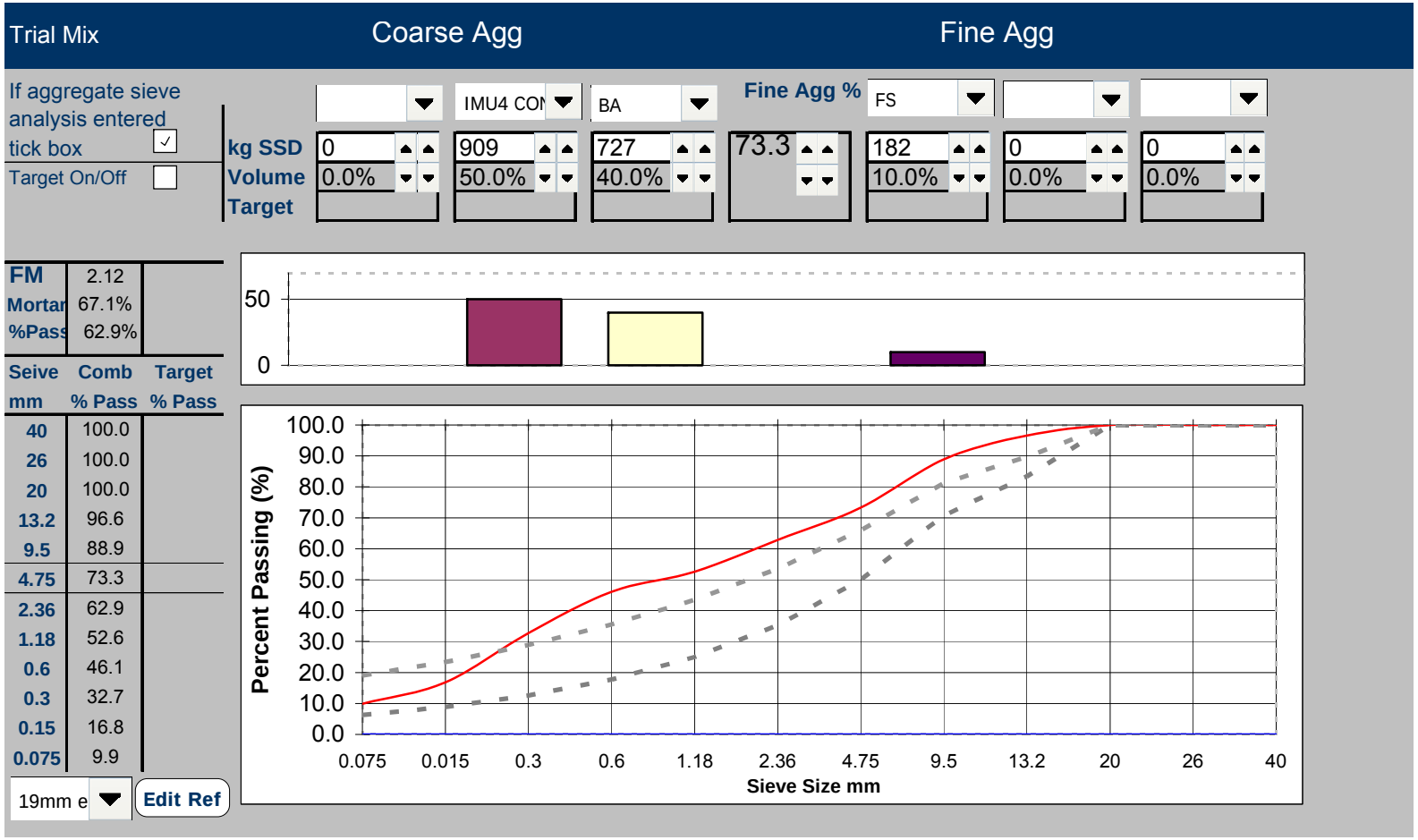
Blend 62


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
910
362
75.9
547
0
0
0.0%
50.1%
19.9%
30.0%
0.0%
0.0%
FM 2.05
Mortar 72.1%
%Pass 69.8%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 97.5
9.5 90.3
4.75 75.9
2.36 67.0
1.18 58.2
0.6 53.0
0.3 34.7
0.15 10.8
0.075 6.8
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

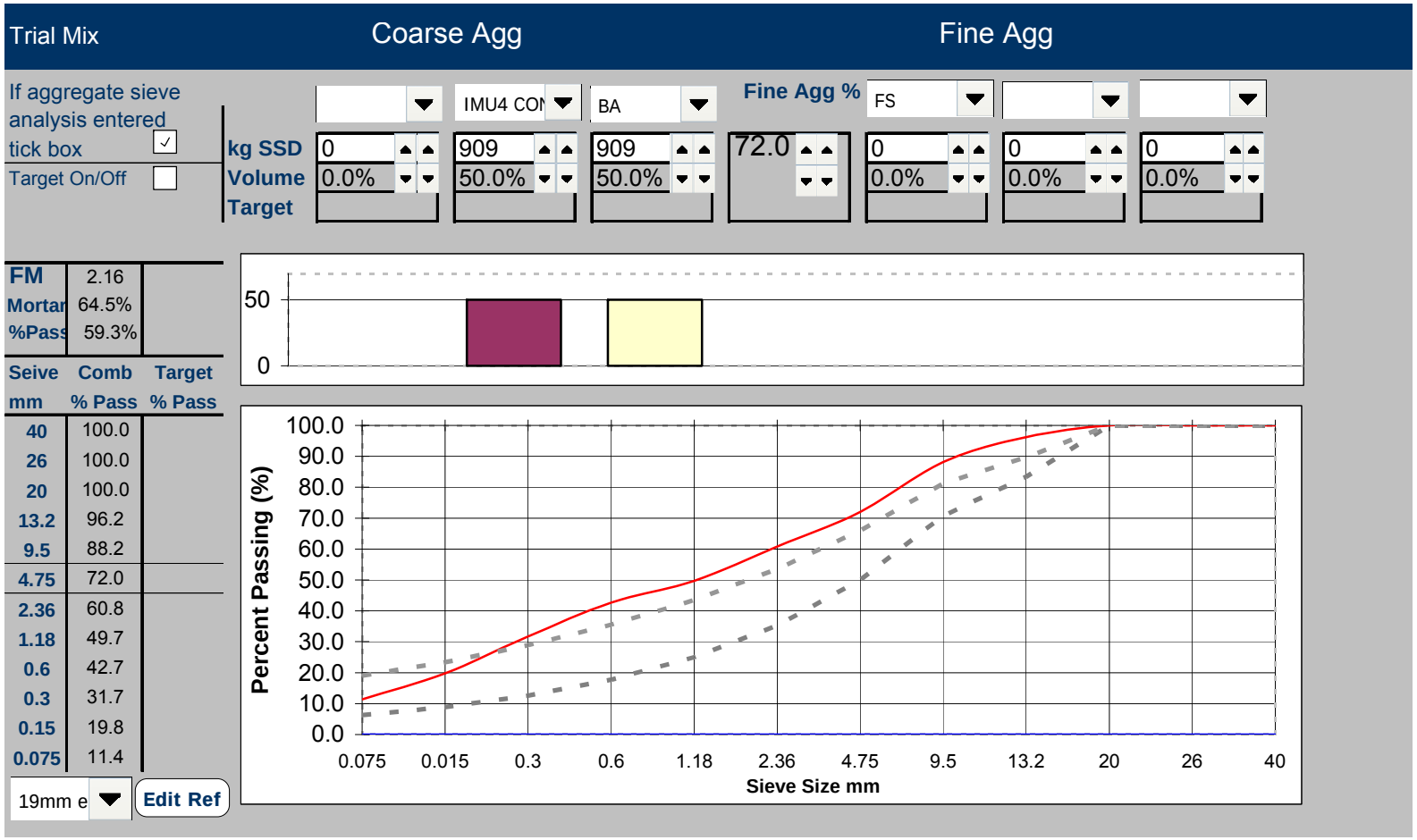
Blend 63

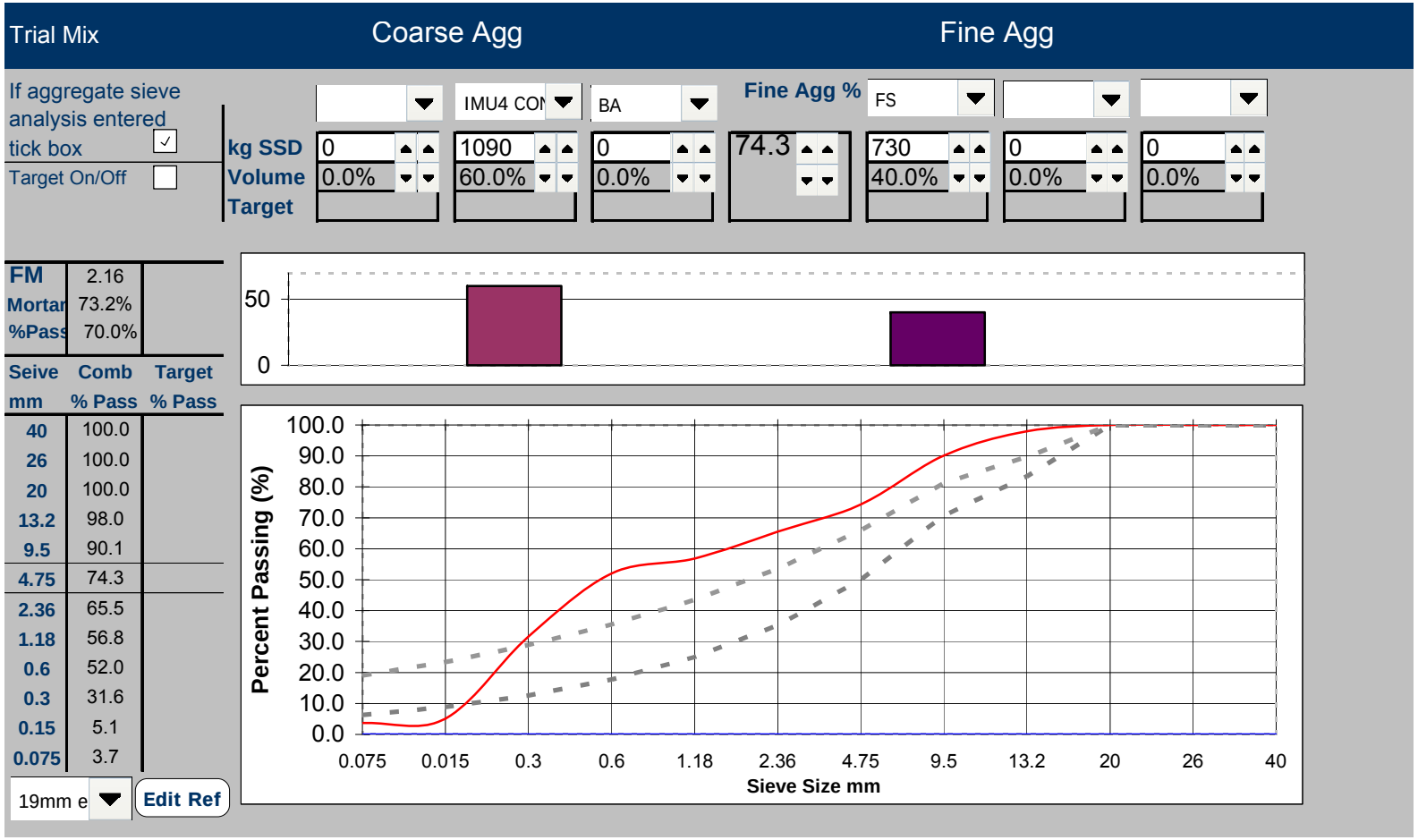

Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
910
544
74.6
365
0
0
0.0%
50.0%
30.0%
20.0%
0.0%
0.0%
FM 2.09
Mortar 69.6%
%Pass 66.4%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 97.0
9.5 89.6
4.75 74.6
2.36 65.0
1.18 55.4
0.6 49.6
0.3 33.7
0.15 13.8
0.075 8.3
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

Blend 64

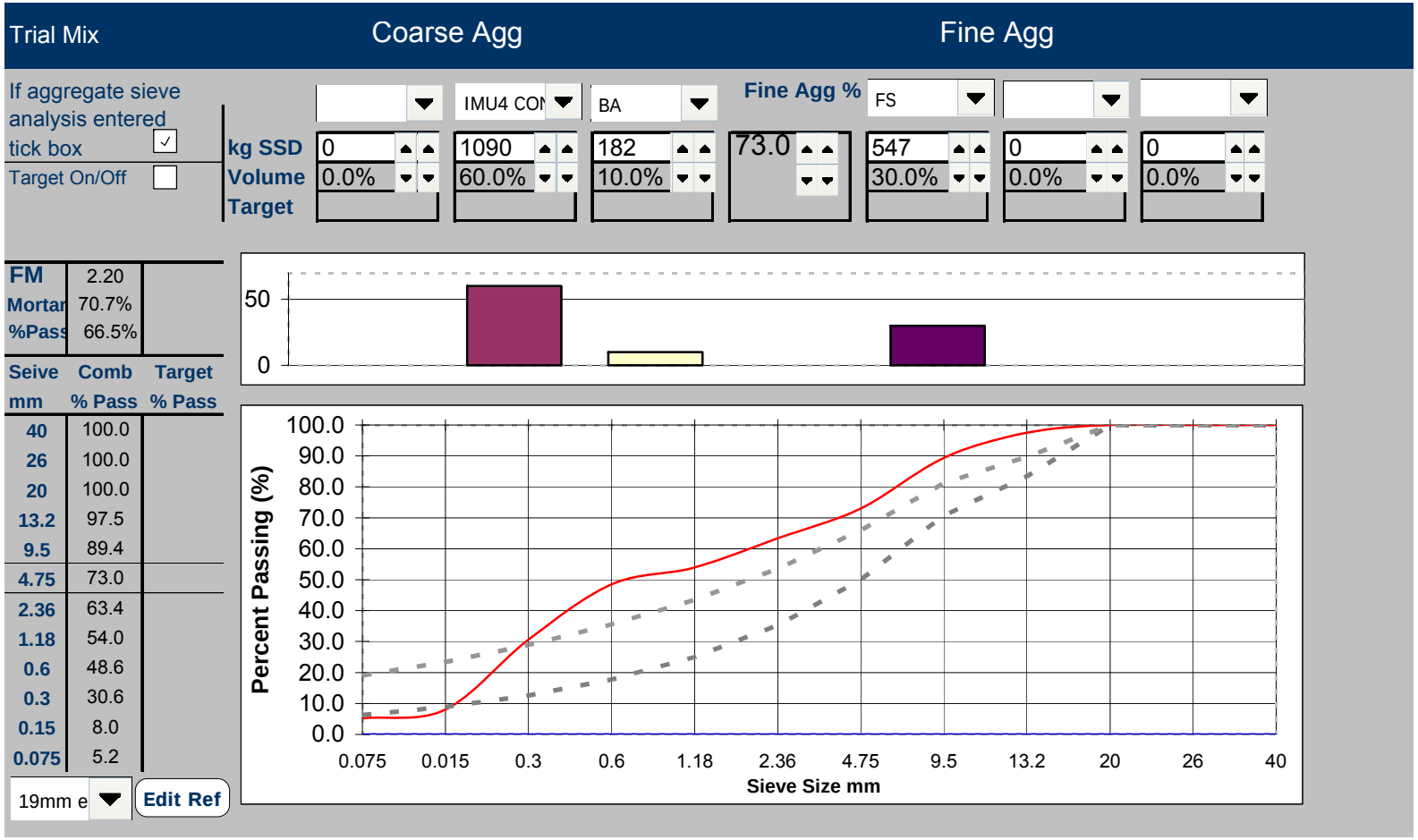

Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
909
727
73.3
182
0
0
0.0%
50.0%
40.0%
10.0%
0.0%
0.0%
FM 2.12
Mortar 67.1%
%Pass 62.9%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.6
9.5 88.9
4.75 73.3
2.36 62.9
1.18 52.6
0.6 46.1
0.3 32.7
0.15 16.8
0.075 9.9
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

Blend 65

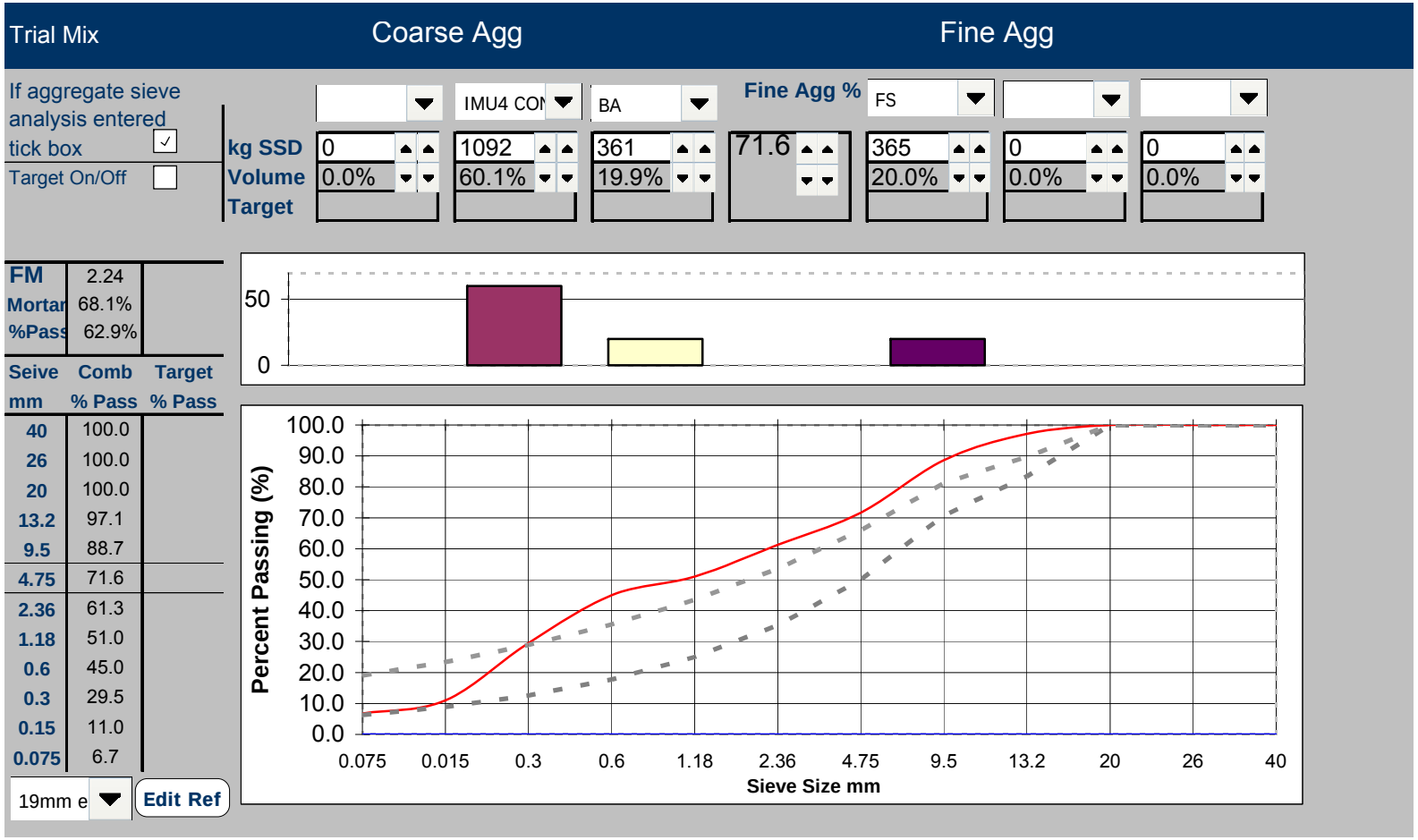

Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
909
909
72.0
0
0
0
0.0%
50.0%
50.0%
0.0%
0.0%
0.0%
FM 2.16
Mortar 64.5%
%Pass 59.3%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.2
9.5 88.2
4.75 72.0
2.36 60.8
1.18 49.7
0.6 42.7
0.3 31.7
0.15 19.8
0.075 11.4
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1090
0
74.3
730
0
0
0.0%
60.0%
0.0%
40.0%
0.0%
0.0%
FM 2.16
Mortar 73.2%
%Pass 70.0%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 98.0
9.5 90.1
4.75 74.3
2.36 65.5
1.18 56.8
0.6 52.0
0.3 31.6
0.15 5.1
0.075 3.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

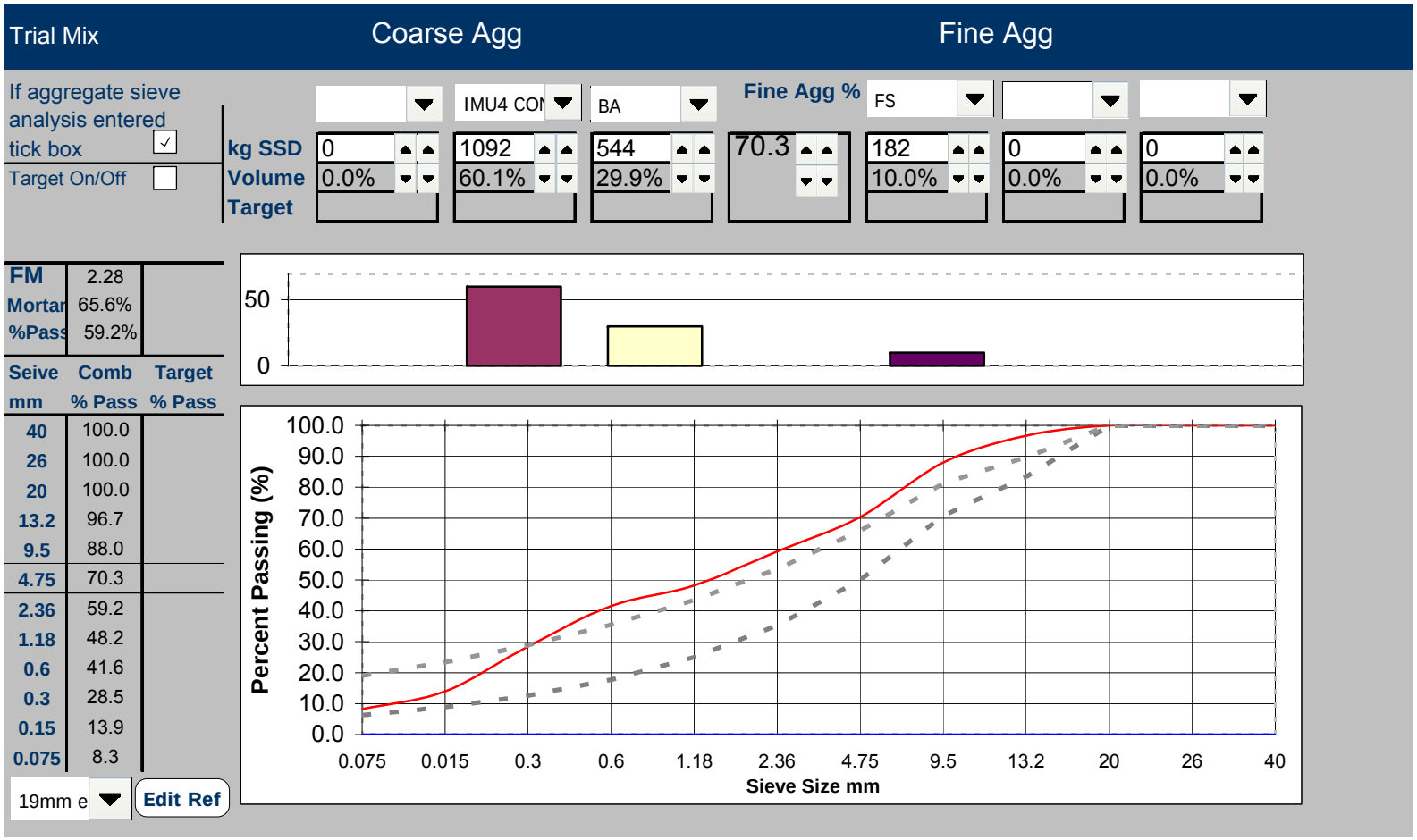
Blend 67


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1090
182
73.0
547
0
0
0.0%
60.0%
10.0%
30.0%
0.0%
0.0%
FM 2.20
Mortar 70.7%
%Pass 66.5%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 97.5
9.5 89.4
4.75 73.0
2.36 63.4
1.18 54.0
0.6 48.6
0.3 30.6
0.15 8.0
0.075 5.2
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

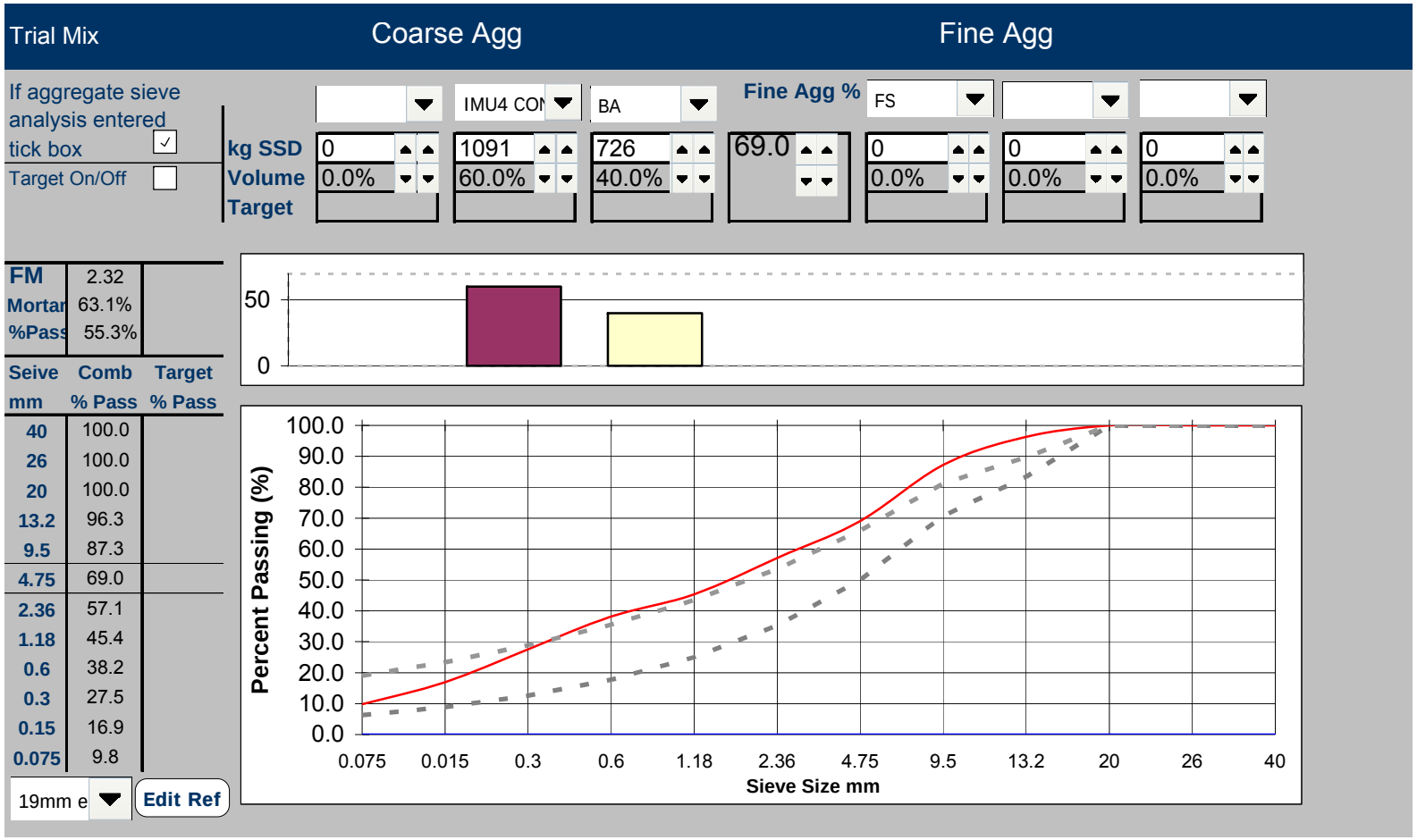
Blend 68


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1092
361
71.6
365
0
0
0.0%
60.1%
19.9%
20.0%
0.0%
0.0%
FM 2.24
Mortar 68.1%
%Pass 62.9%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 97.1
9.5 88.7
4.75 71.6
2.36 61.3
1.18 51.0
0.6 45.0
0.3 29.5
0.15 11.0
0.075 6.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

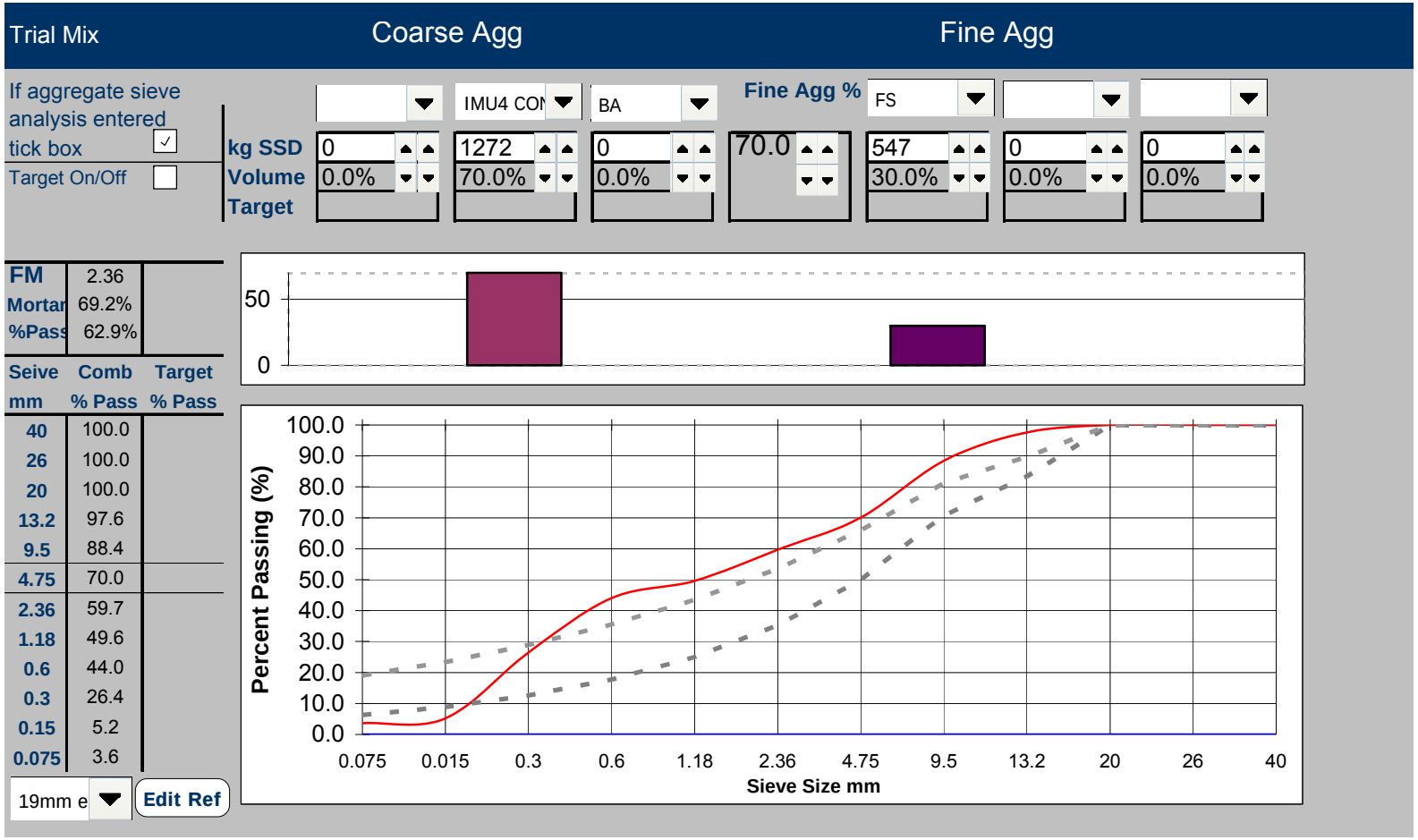
Blend 69


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1092
544
70.3
182
0
0
0.0%
60.1%
29.9%
10.0%
0.0%
0.0%
FM 2.28
Mortar 65.6%
%Pass 59.2%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.7
9.5 88.0
4.75 70.3
2.36 59.2
1.18 48.2
0.6 41.6
0.3 28.5
0.15 13.9
0.075 8.3
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

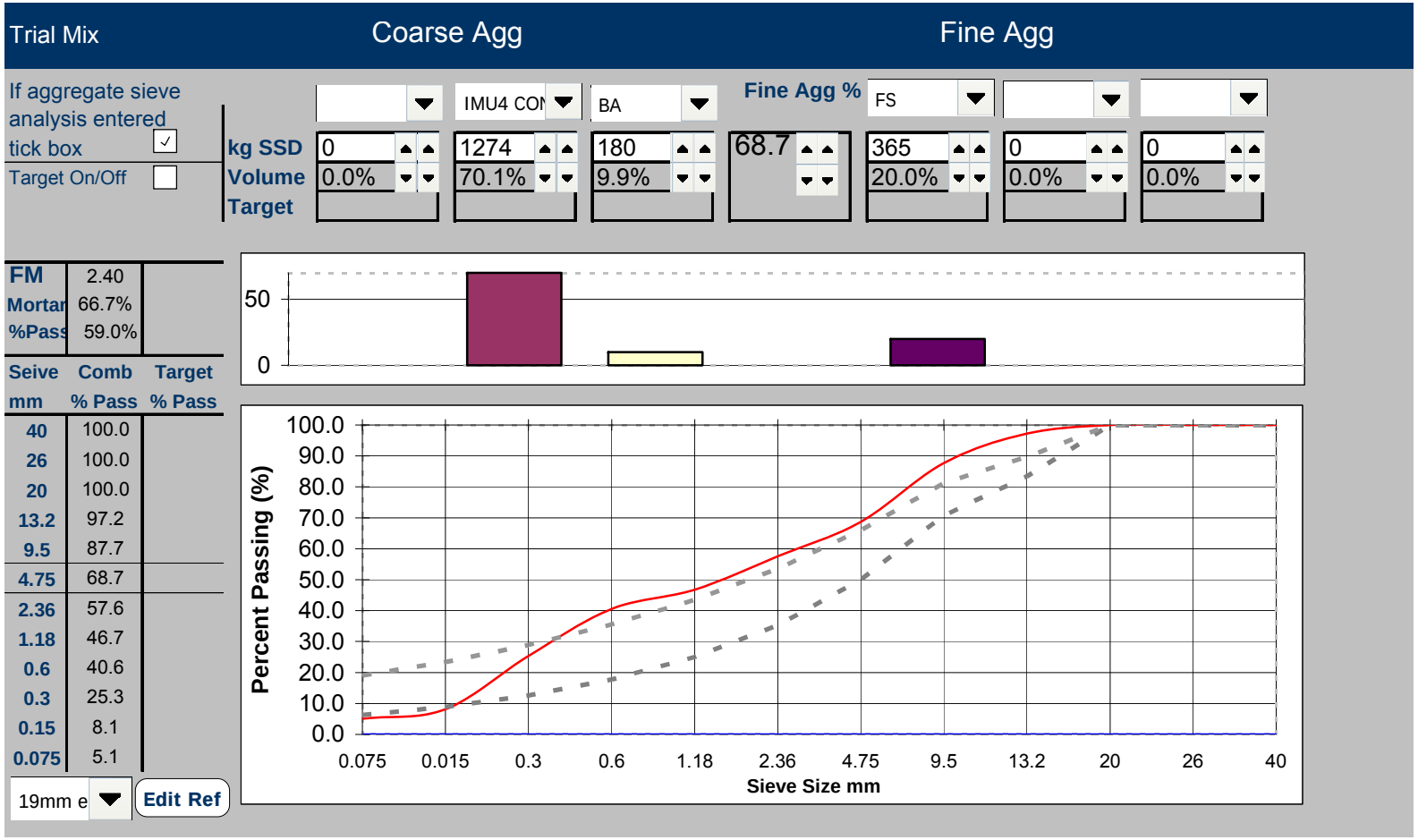
Blend 70


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1091
726
69.0
0
0
0
0.0%
60.0%
40.0%
0.0%
0.0%
0.0%
FM 2.32
Mortar 63.1%
%Pass 55.3%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.3
9.5 87.3
4.75 69.0
2.36 57.1
1.18 45.4
0.6 38.2
0.3 27.5
0.15 16.9
0.075 9.8
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

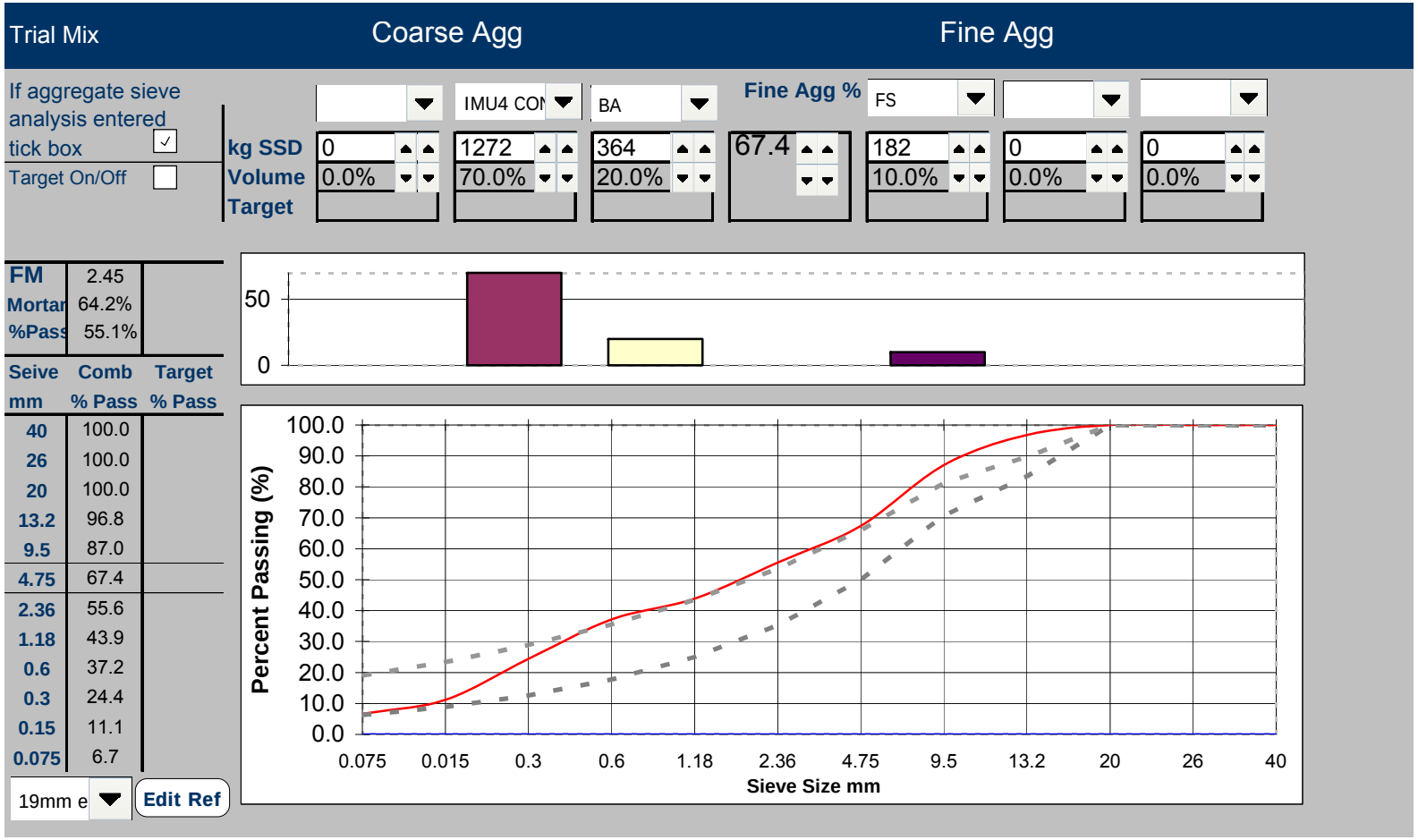
Blend 71


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1272
0
70.0
547
0
0
0.0%
70.0%
0.0%
30.0%
0.0%
0.0%
FM 2.36
Mortar 69.2%
%Pass 62.9%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 97.6
9.5 88.4
4.75 70.0
2.36 59.7
1.18 49.6
0.6 44.0
0.3 26.4
0.15 5.2
0.075 3.6
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

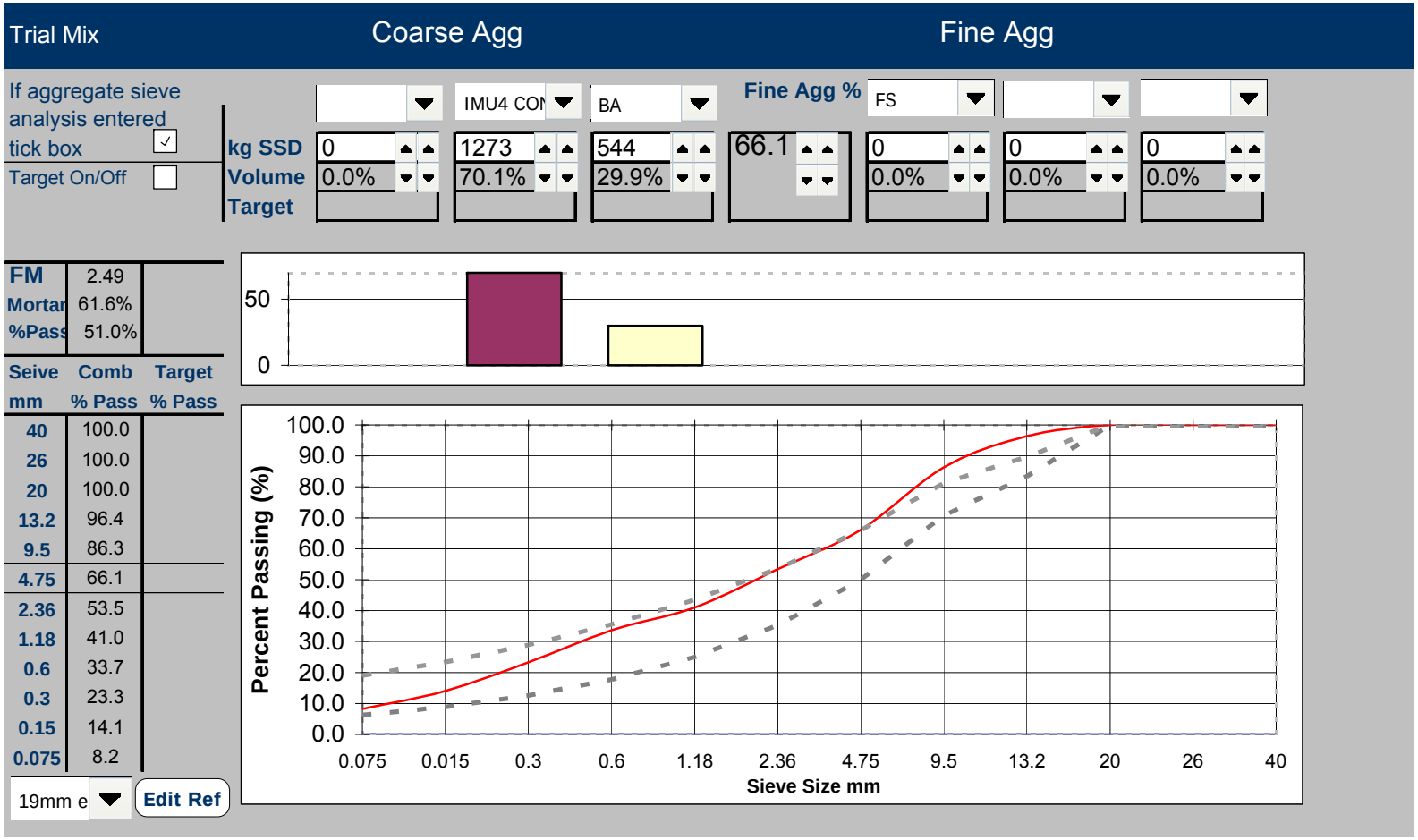
Blend 72


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1274
180
68.7
365
0
0
0.0%
70.1%
9.9%
20.0%
0.0%
0.0%
FM 2.40
Mortar 66.7%
%Pass 59.0%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 97.2
9.5 87.7
4.75 68.7
2.36 57.6
1.18 46.7
0.6 40.6
0.3 25.3
0.15 8.1
0.075 5.1
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

Blend 73


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1272
364
67.4
182
0
0
0.0%
70.0%
20.0%
10.0%
0.0%
0.0%
FM 2.45
Mortar 64.2%
%Pass 55.1%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.8
9.5 87.0
4.75 67.4
2.36 55.6
1.18 43.9
0.6 37.2
0.3 24.4
0.15 11.1
0.075 6.7
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

Blend 74


Trial Mix
Coarse Agg
Fine Agg
If aggregate sieve analysis entered tick box
Target On/Off
IMU4 CON
BA
Fine Agg %
FS
kg SSD
Volume
Target
0
1273
544
66.1
0
0
0
0.0%
70.1%
29.9%
0.0%
0.0%
0.0%
FM 2.49
Mortar 61.6%
%Pass 51.0%
Seive mm
Comb % Pass
Target % Pass
40 100.0
26 100.0
20 100.0
13.2 96.4
9.5 86.3
4.75 66.1
2.36 53.5
1.18 41.0
0.6 33.7
0.3 23.3
0.15 14.1
0.075 8.2
19mm e
Edit Ref
50
0
Percent Passing (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.075
0.015
0.3
0.6
1.18
2.36
4.75
9.5
13.2
20
26
40
Sieve Size mm

Blend 75